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CORRECTIVE ACTION PLAN ADDENDUM

Former Santa Rosa Imports
421 Santa Rosa Avenue
Santa Rosa, California 95404
Case No. 1TSR059
Clearwater Project # AB021E

Prepared for:

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February 17, 2005

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1.0 INTRODUCTION

1.1 Purpose

This report was prepared by Clearwater Group (Clearwater) on behalf of Spaceco Storage and Mr. Franklin Wolmuth. Clearwater presents this Corrective Action Plan Addendum for 421 Santa Rosa Avenue, Santa Rosa, Sonoma County, California (the "site" – Refer to Figure 1). The California Regional Water Quality Control Board, North Coast Region (NCRWQCB) requested this Corrective Action Plan in a letter dated December 8, 2004 (included in attachments)

1.2 Scope of Work

In this Corrective Action Plan Addendum, Clearwater reviews three types of remediation technologies (excavation, chemical oxidation, and enhanced bioremediation). As part of developing the remediation solution for the site, Clearwater is proposing to perform an Interim Remedial Investigation in this CAP Addendum report to close data gaps and refine the remediation methods/technologies (described below in Tasks 1 to 3) that will be selected in the future Remedial Action Plan (RAP) and implementation (described below in Tasks 4 to 5). Groundwater monitoring will continue (Task 6).

Task 1 – Corrective Action Plan Addendum (This report)

Clearwater will evaluate various remedial approaches for the site (this report) according to the requirements of Title 23, Article 11, Section 2725. The Feasibility Study portion of the CAP Addendum discussed in Sections 5 through 7 evaluates and compares cleanup alternatives and the costs for the life of the project, including ongoing monitoring and reporting costs.

Task 2 – Interim Remedial Investigation

Clearwater will drill nine soil borings to obtain continuous lithologic information prior to preparing the Remedial Action Plan. Three of them will be converted into monitoring wells. Detailed cross sections will be prepared.



Task 3 – Collect Indirect Geochemical Indicators for Background Levels

Clearwater will collect enhanced bioremediation information during the time the next sampling event.

Task 4 – Remedial Action Plan

Clearwater will prepare a Remedial Action Plan based on Tasks 1 through 3, above, with recommendations and detailed costs, schedules and diagrams.

Task 5 – Remedial System Installation

Clearwater will perform the appropriate remediation activities as described in the Remedial Action Plan (Task 4).

Task 6 – Groundwater Monitoring

Clearwater will continue with existing groundwater monitoring during the remedial process, until an approval of cessation of groundwater monitoring is granted by the NCRWQCB. The groundwater sampling will include EPA Method 8260 for fuel oxygenates and lead scavengers. Clearwater will coordinate sampling and monitoring activities with the consultant for the adjacent property at 505 Santa Rosa Avenue, Santa Rosa.



2.0 SITE DESCRIPTION AND HISTORY

The site is located on the northwest corner of Santa Rosa and Sebastopol Avenues in Santa Rosa, Sonoma County, California (Figure 1). It is set in an area of combined residential and commercial use. Regional topography slopes gently toward the west. A former service station building exists on-site and is currently used as an automobile repair shop. An additional on-site building is currently used as a Greyhound Bus terminal. A site map is shown in Figure 2.

In July 1988, the underground storage tanks (UST) were removed from the site. Three 10,000-gallon gasoline USTs were removed from a common excavation in the southern portion of the site, and one 550-gallon used oil UST was removed from another excavation in the western portion of the site (Figure 2). Associated product dispensing / vent lines and dispensers were also removed. Analytical results for soil samples collected from beneath the USTs during removal indicated elevated concentrations of petroleum hydrocarbons.

2.1 Previous Investigations

Previous analytical, groundwater elevation and well construction data tables are included in Appendix A. Previous investigations are described below.

Harding Lawson and Associates (HLA) of Novato, California conducted a site investigation in 1989. HLA performed a preliminary site assessment with hand-augered shallow boreholes (B-1 through B-13) in locations near the former UST location and dispensing lines (Figure 2). The results of HLA's work were presented in their report dated April 24, 1989.

GeoPacific Investigations (GPI) of Novato, California installed three monitoring wells (MW-1 through MW-3) and drilled three additional soil borings (SB-1 through SB-3) in September 1991 (Figure 2). Results of this work were presented in GPI's report for an *Initial Hydrogeologic Investigation for an Unauthorized Release of Petroleum Constituents* dated May 8, 1992. Groundwater monitoring well sampling also occurred during 1991 to 1994. GPI drilled additional soil and hydropunch borings (SB-14 through SB-28) in September 1994 to further



characterize the extent of soil and groundwater contamination. Results of this work were presented in GPI's *Subsurface Soil/Groundwater Investigation* report dated September 22, 1994.

GPI directed excavation of contaminated soil in the area of the former USTs and dispensers during site remodeling efforts in 1996. During construction of a new Greyhound terminal in early 1996, crews encountered older dispenser lines and contaminated soil in the vicinity of the former southern dispenser island (Figure 2). Based on these observations, the Santa Rosa Fire Department requested removal of the lines and over-excavation of any associated contaminated soil. In February and May 1996, GPI supervised the over-excavation of approximately 400 cubic yards (cu. yd.) of soil from this area. The excavation did not extend deeper than 5 feet below ground surface (bgs). Approximately 250 cu yd of soil were transported to Redwood Landfill in Novato, California for disposal and the remaining 150 cu yd were aerated on-site to non-detectable concentrations of gasoline hydrocarbons, and then used as excavation backfill. Results of this work were presented in GPI's *Report for Over-excavation of Petroleum Hydrocarbon Contaminated Soils* dated August 14, 1996.

Additional over-excavation activities were performed in late 1996. GPI supervised the excavation of approximately 1,000 to 2,000 cu yd of additional soil (Figure 2). The maximum depth of the excavation was between 5 to 7 feet bgs. The work was performed in six phases consisting of excavation and aeration of approximately 150 to 200 cu yd at a time. Excavated soil was aerated between 4 and 7 days prior to confirmation sampling. Nearly all of the excavated soil was used as backfill following aeration. Approximately 300 to 400 cu yd of surplus excavated soil was transported to Redwood Landfill for disposal. Results of this work were presented in GPI's *Report for Additional Over-excavation of Petroleum Hydrocarbon Contaminated Soils* dated November 11, 1996.

In May 2000, Clearwater oversaw the proper destruction of wells MW-1 and MW-2, which had been damaged during excavation and site redevelopment work. Well MW-3, also damaged and covered during site work, could not be located and thus has been abandoned in place. Clearwater



supervised the installation of two replacement wells (MW-1A and MW-2A), and four additional plume delineation wells (MW-4 through MW-7). Results of these efforts were presented in Clearwater's *Additional Subsurface Investigation Report* dated May 31, 2000.

In December 2000, Clearwater supervised the installation of two additional downgradient plume delineation wells (MW-8 and MW-9). Results of these efforts were presented in Clearwater's *Problem Assessment and Groundwater Monitoring Report (Fourth Quarter 2000)* dated December 29, 2000. Clearwater has been sampling the groundwater monitoring wells on a regular basis since May 18, 2000.

2.2 Summary of Feasibility Testing

Clearwater's evaluation of remedial action alternatives was described in the *Workplan for Remedial Feasibility Testing* dated on March 27, 2000. An additional workplan was prepared in October 29, 2003 for the installation of the soil vapor extraction (SVE) well, EW-1. Feasibility testing of extraction technologies was performed on the site in 2003-2004. The extraction technologies included soil vapor extraction (SVE) for the vadose zone and groundwater extraction (GWE) for the saturated zone.

Drilling and Well Installation (EW-1)

On October 29, 2003, Clearwater supervised Clearheart Drilling, of Santa Rosa, California. Clearheart is a California C-57 licensed contractor for water well drilling. Clearheart used a CME 75 truck-mounted drill-rig equipped with hollow-stem augers to drill the boring and install the four-inch diameter, 25-foot deep extraction well EW-1.

Feasibility Testing

Clearwater tested active extraction technologies on site for remediation options by performing feasibility testing. The groundwater extraction test evaluated the pump and treat option. The soil vapor extraction test evaluated the SVE option.

SVE Testing

On August 29, 2004, Clearwater performed SVE testing of EW-1. An electric blower (Ametek EN454M) was connected to the wellhead, inducing a vacuum. During testing, Clearwater



measured the vacuum and airflow rate at the wellhead of EW-1. The measured vacuum observed at the inlet of the blower during the test was 40 inches of water; the airflow rate was approximately 5 cubic feet per minute (cfm). Vacuum at a nearby well (MW-1A), and several "out-lying" wells (MW-2A, MW-6, and MW-7) was measured using magnehelic gauges to determine radius of influence. The SVE test was run for approximately 2 hours. Extracted air was treated with two vapor-phase Granular Activated Carbon (GAC) canisters (in-series) prior to discharge to the atmosphere, and all appropriate agencies were notified prior to the start of the test. The observed air flow rate from the SVE feasibility test suggests that standard SVE is not practicable at this site, as a large number of extraction wells would be required to generate a significant flow of soil vapor from the subsurface.

Induced vacuum measured at observation points (MW-1A, MW-2A, MW-6, and MW-7) throughout the test suggest that extraction from EW-1 with an applied vacuum of 40 inches of water results in an effective radius of influence of less than 10 feet. No vacuum effect was measured in any of these wells during the SVE test, even in MW-1A, which is located approximately 10 feet from EW-1. An effective radius of influence for SVE is generally accepted as greater than 0.1 inches of water of induced vacuum at an observation point. Radius of influence data also suggest that SVE may not be practicable at this site due to the large number of extraction wells that would be required to generate a significant air flow and to affect sufficient soil volume.

Contaminant recovery rates for SVE are likely to be relatively modest, based on low airflow rates and relatively low extractable contaminant concentrations in the air stream. The air sample collected during the GWE/SVE test contained 22 mg/m³ of TPHg. Thus, TPHg recovery rates from one extraction well would be ~0.01 lbs/day, assuming an air flow rate of 5 cfm and air TPHg concentration of 22 mg/m³. Even with a grid of 13 extraction wells, TPHg recovery rates would only be ~0.13 lbs/day. These contaminant recovery rates do not appear to be sufficient to justify the use of SVE at the site.

Groundwater Extraction Test (EW-1)

On August 29, 2004, Clearwater performed a brief drawdown test on EW-1, which allowed for rough determination of sustainable flow rates and specific capacity for the well. Groundwater extraction was only considered at the site for dewatering a portion of the saturated zone in order



to expose more contaminated soil for vapor extraction, thus, longer term pumping tests used to determine hydrogeologic parameters and capture zone were not tested at this time. Details of the groundwater extraction testing are found in previous reports.

The feasibility test was performed in steps by pumping water from the well started with a flow rate of approximately 1 gallon per minute by using an electric submersible pump and monitoring depth to water in the pumping well with a water-level indicator. The test was performed over the course of approximately 20 minutes, and approximately 20 gallons of water were extracted from EW-1. A maximum drawdown of approximately nine feet was observed at the end of the test. Based on the flow rate, discharge volume, and drawdown, potential yield from EW-1 is anticipated to be below 0.5 gallons per minute.

The results of the step drawdown test on EW-1 indicate that a low pumping rate could sufficiently dewater the well for the purposes of enhancing soil vapor extraction. However, the results also indicate that the soil under the site has very low permeability and groundwater extraction would not be economically or technically feasible.

Conclusions of Extraction Feasibility Testing

These results suggest that the effectiveness of any remedial technology relying on extraction and relatively high soil permeability will be limited, unless designed with a large number of extraction points. Based on these results and past experience, neither groundwater extraction nor soil vapor extraction appear to be feasible for the remediation of this site.



3.0 SUMMARY OF HYDROGEOLOGY AND CONTAMINATION

3.1 Hydrogeology

The site is underlain predominantly by clay to a depth of approximately 17 feet bgs. A sand layer underlies the clay to a depth of approximately 20 feet bgs. Depth to groundwater has historically ranged from approximately 5 to 14 feet bgs, with flow toward the northwest and north-northwest. A recently monitored groundwater elevation contour map is presented in Figure 3.

3.2 Contaminants of Concern

The predominant contaminants, which appear to have been released to the subsurface from the former UST system, consist of gasoline compounds. Specific compounds or compound groups, which have been consistently detected, include total petroleum hydrocarbons as gasoline (TPHg), and benzene, toluene, ethylbenzene, and total xylenes (BTEX). Methyl tertiary butyl ether (MTBE) has been detected by EPA Method 8260 in groundwater at a maximum concentration of 44 micrograms per liter ($\mu\text{g/L}$) in monitoring well MW-9 sampled on January 8, 2003. Clearwater also analyzed for tert-butyl alcohol (TBA), a breakdown product of MTBE.

3.3 Distribution and Mass of Sorbed-Phase Contaminants

The extent of residual sorbed-phase contaminants has been determined. The "footprint" of sorbed-phase contaminants resembles an ellipse, elongated toward the south. The lateral extent of these contaminants appears to be restricted to just beneath the subject property. Sorbed-phase contaminant concentrations appear to be greatest at the average depth of the capillary fringe (i.e., approximately 7.5 to 10 feet bgs); however, the total thickness of contaminated soil ranges from approximately 7.5 to 15 feet bgs, with a shallower pocket of contamination present beneath the service bay building from approximately 5 to 15 feet bgs.

The total volume of soil impacted by TPHg concentrations greater than 10 milligrams per kilogram (mg/kg) is estimated at approximately 63,000 cubic feet (cu ft) (or 2,300 cu yd) in-situ. This impacted soil volume contains approximately 1,716 pounds (lb) of gasoline hydrocarbons (or 281 gallons [gal.]).



3.4 Distribution and Mass of Contaminants in Groundwater

The extent of the dissolved-phase contaminant plume coincides with the general "footprint" of sorbed-phase contaminants, but the edges of the dissolved-phase plume are more widespread. Maximum TPHg and benzene concentrations detected in existing on-site wells have been 86,000 $\mu\text{g/L}$ and 17,000 $\mu\text{g/L}$, respectively, in monitoring well MW-1A as sampled on May 18, 2000. However, dissolved-phase contaminants appear to be restricted mostly to site boundaries. It is estimated that on the order of 520,000 gal. of groundwater are affected by TPHg concentrations greater than 100 $\mu\text{g/L}$, and that on the order of 26 lb (or 4 gal.) of gasoline contaminants reside in the dissolved-phase.

3.5 Empirical Determination of Contaminant First-Order Decay Rates

If natural attenuation or biodegradation is occurring within a plume, a reduction of hydrocarbons concentrations or mass is usually observed over time. It usually occurs at a site, which has experienced source removal and/or some active remediation. If natural attenuation or biodegradation occurs, the rates actually overtake the rate at which petroleum hydrocarbons released from the sorbed-phase into the dissolved-phase. The process that hydrocarbons degrade often takes place at a first-order kinetics. First-order degradation rate can be determined by evaluating the change of either hydrocarbon concentrations from individual wells or total plume mass with time, if the plume has been delineated for an extended period of time. First-order degradation rates for the petroleum hydrocarbons beneath this site were estimated by using historical monitoring data obtained from well MW-1A.

Concentrations of TPH-g and benzene measured at MW-1A were plotted against time as a semi-log function. A degradation rate was determined by fitting a first-order kinetic equation to the plotted data. The method indicates that the plotted data are highly correlated with the first-order kinetic equation. The estimated first-order degradation rates for TPH-g and benzene in MW-1A are 0.0579 per day and 0.1444 per day, respectively. The results are shown in Figure 5.



4.0 OVERVIEW OF APPLICABLE REMEDIAL OPTIONS

The main benefits of in-situ remediation systems over more conventional methods are the lower final cost for remediation, minimum cost for operations and maintenance, lesser need for discharge permits or disposal of waste liquids. However, in-situ remediation programs require detailed understanding of the lithology and hydrogeology of the subsurface.

In-situ treatment technologies can be an attractive alternative when on-site activities or structure precludes more conventional remediation methods, relatively deeper or impermeable soils are impacted, and/or when time constraints are not an issue. This is certainly the case on the subject property where two businesses exist. The key to the injection of liquids or gases for in-situ remediation of soil and groundwater is achieving proper exposure of the treatment chemicals and amendments to the contaminated soil and groundwater, regardless of the delivery method used. Treatment chemicals can be injected to favorably enhance a number of chemical and biological processes: chemical oxidation and enhanced biodegradation.

Based on the feasibility testing and lithologic information collected, Clearwater reviewed three general methods for soil and/or groundwater remediation that might be applicable for the site.

4.1 Excavation

Shallow excavation has already occurred in the source zone to a maximum depth of about 7 feet. Excavation can be used for remediation of the source area. The disruption to site activities for a large-scale excavation would be significant and remedial measures discussed in this report are focused on minimizing on-site disruption to the two tenants: the Greyhound Bus Station and the vehicle repair shop. A limited or "surgical" excavation will be considered if the additional subsurface data from Task 2 indicates a significant buried source with a limited aerial extent.

4.2 Chemical Oxidation

Chemical oxidizers, such as hydrogen peroxide/Fenton's Reagent are quite powerful for rapid degradation of hydrocarbon contaminants in both soil and groundwater. Potassium permanganate is also an oxidant frequently used on hydrocarbons as well as chlorinated solvents, but not methyl tertiary butyl ether (MTBE). The other oxidant worthy of evaluation is ozone,



which is generated on site as a gas and injected to wells or well points. These techniques are difficult to control and the reaction times (half-life) of ozone and hydrogen peroxide would preclude much migration through low permeability soil. Therefore, due to the rapid reaction of the chemical oxidant with contaminants or natural organics in subsurface, injected oxidants could be quickly consumed prior to migrating more than a few feet beyond the injection ports. The day-use of the property would be interrupted during ozone, peroxide, or Fenton injection; and liquid surfacing is another potential problem for liquid oxidants that are injected into the ground under pressure. Given the safety concerns of chemical oxidants, the likelihood of marginal results, and the active tenant use of the property, this approach is not being pursued at this time.

4.3 Enhanced Bioremediation

Enhanced bioremediation is primarily a groundwater remedial method. Given the low permeability, natural attenuation (degradation without the addition of electron acceptors, such as oxygen) or enhanced bioremediation (the addition of an electron acceptor such as oxygen) is a viable option in the groundwater zone wherein naturally occurring microbes consume the oxygen in the system and use the hydrocarbon as a food source. The oxygen molecule and microbe size is smaller than the openings between the clay particles. Therefore, oxygen can migrate through the low permeability aquifers. Clearwater performed an enhanced bioremediation study in July 2004 during the quarterly sampling event. Based on the characteristics of the site and applicability and limitations of these three remedial technologies, enhanced bioremediation is considered as the most appropriate method for groundwater remediation at the site for the majority of the residual hydrocarbons.

5.0 BIOREMEDIATION PROCESSES

Natural attenuation is unenhanced physical, chemical and biological processes that act to limit the migration and reduce the concentration of contaminants in the subsurface (Testa, 1996). The most important process with respect to petroleum hydrocarbons is aerobic bioremediation because it is capable of destroying a large percentage of the hydrocarbon contaminant mass. Destruction occurs as a result of bacteria oxidizing reduced materials (i.e., hydrocarbons) to obtain energy. Aerobic biological degradation of fuel hydrocarbons and selected other organic compounds have been well documented (Rice, et. al., 1995, Mace, et. al., 1997). Supplying the appropriate amount of oxygen, nutrients and other amendments to the subsurface can enhance the biodegradation process, and significantly increase remediation effectiveness and decrease treatment time.

Monitored natural attenuation (MNA) and enhanced bioremediation of dissolved hydrocarbon plumes is a function of several factors including aerobic and anaerobic biodegradation, volatilization, dispersion/advection, and sorption (McAllister and Chiang, 1994). Although all of these factors contribute to actual or apparent removal of contaminant mass from the dissolved-phase, only biodegradation processes were examined in this study as they, particularly aerobic biodegradation processes, tend to be the most significant and/or rapid processes, and thus have the greatest potential for ongoing remediation through natural attenuation. However, all of the processes are described briefly below to provide a general background. The MNA monitoring results follow. A detailed discussion of MNA is included with Clearwater's protocols in Appendix C.

5.1 Physical Processes

Physical processes include sorption, volatilization, and advection/dispersion. Sorption temporarily reduces the dissolved concentration and does not destroy the contaminant mass. It typically affects only a small fraction of the plume mass. It generally does not play a major role in the ongoing attenuation of the plume, except possibly at the plume edges if the plume continues to migrate. Sorption generally occurs early in the spill history, as contaminated groundwater comes in contact with clean soils.



Volatilization of dissolved contaminants may play a significant role in the natural attenuation of volatile organic constituents such as benzene. Volatilization can be estimated using a formula which takes into account the observed mass loss (contaminant decay rate); however, volatilization has been demonstrated to account of only 5% of benzene mass loss at a site with relatively favorable conditions for this process (Chiang, C.Y. et al, 1989).

Advection/dispersion is responsible for the off-site migration of contaminants. Like adsorption, it may reduce the plume concentrations; it does not reduce the mass of contaminants. To evaluate the extent of a plume attenuated through advection, the dissolved constituents are assumed to move at the same velocity as the groundwater (i.e. no retardation). Using the hydraulic conductivity of the water bearing zone, average hydraulic gradient, and average effective porosity, an approximate volume of hydrocarbons migrating off site can be estimated using Darcy's Law. However, this process relies on "dilution" and is not acceptable at most sites.

5.2 Biodegradation Processes and Indicators

The use of terminal electron acceptors (TEAs) such as dissolved oxygen, have been used to enhance natural attenuation of fuel hydrocarbons, including gasoline constituents benzene, toluene, ethylbenzene and total xylenes (BTEX), methyl tertiary butyl ether (MTBE) and tertiary butyl alcohol (TBA). In-situ bioremediation technology has been extensively studied since the mid 1990's. Significant documentation describes the details of microbial degradation processes of hydrocarbons, solvents and other substances: Beek (2001), Freeze and Cherry (1979), Chapelle (1993), Levin and Gealt (1993), McCarty, P.L., and de la Torre (2000), Suthersan (2002), and Wiedemeier et al., (1999).

During biodegradation, microbes utilize electron acceptors to convert hydrocarbons to carbon dioxide, water, and biomass. In aerobic degradation, the electron acceptor is dissolved oxygen (DO). In anaerobic degradation, compounds other than oxygen are used as electron acceptors. The reactions that yield the most energy take precedence over those reactions that yield less energy (except for denitrification which yields the most free energy but will not occur if oxygen

concentrations are >0.5 mg/L). This results in electron acceptors being used up in the following preferential order: oxygen, nitrate, ferric-iron oxides, sulfate, and carbon dioxide (methanogenesis). Since oxygen and nitrate are toxic to sulfate-reducing organisms, sulfate cannot be used as an electron acceptor until oxygen and nitrate have been sufficiently depleted (Wiedemeier et al., 1994). Metabolism through iron reduction uses ferric-iron oxides and produces ferrous iron (dissolved) as a byproduct.

Reduction-oxidation potential (ORP) is a measure of the electron activity in a solution. As electron acceptors are consumed within the plume during biodegradation, ORP will drop within the plume. Each biochemical pathway has an associated range of ORP values, depending on the influx of electrons to the system by groundwater recharge. ORP values can thus be used to confirm the active biochemical pathway(s) determined on the basis of electron acceptor depletion. Alternatively, when electron depletion data is inconclusive due to high groundwater recharge, biodegradation can be confirmed and the active biochemical pathway can be assessed by evaluating ORP values.

Alkalinity in the groundwater reacts with organic acid byproducts of biodegradation and thus acts as a buffering agent to maintain pH levels suitable for microbes. This reaction causes alkalinity to decrease in the presence of biodegradation. With sufficient alkalinity present to buffer the products of biodegradation, pH values remain constant inside and outside of the plume. Groundwater pH values determined by measurements made in the field are within normal ranges for aerobic bioremediation. If the groundwater does not contain sufficient alkalinity, the organic acids may build up, reducing the pH and eventually creating an environment inhospitable to the hydrocarbon-utilizing microbes.

5.3 Microbiological Study

A Microbiological Study was performed to define pre-remediation background levels, verify site geochemical conditions and to evaluate the potential for in-situ bioremediation of the Subject Property. The summary of the various analyses is included in Appendix A, which was included



in the Quarterly Groundwater Monitoring Report for the June 24, 2004 sampling date. The June 24, 2004 sampling was a preliminary screening for enhanced bioremediation, in which only selected indirect geochemical indicators have been performed. The initial evaluation of in-situ groundwater bioremediation effectiveness relates to site characteristics and constituent characteristics (U.S. E.P.A., 1995).

Site characteristics include hydraulic conductivity and soil structure, groundwater mineral content, groundwater pH and temperature, microbial presence, terminal electron acceptors, and nutrient concentrations. Constituent characteristics include chemical structure, concentration and toxicity and solubility.

MICROBIAL DATA

Most soils contain large numbers of diverse microorganisms, including bacteria, algae, fungi, protozoa and actinomycetes (U.S. EPA, 1995). Of these, bacteria are the most numerous and biochemically active group, particularly at low oxygen levels, and they contribute significantly to in-situ groundwater bioremediation. Bacteria enumeration data was generated by CytoCulture Environmental Technology, a microbiology laboratory. CytoCulture report dated July 13, 2004 (Report No. 04-90) is attached to the quarterly monitoring report for the June 24, 2004 sampling event. A more direct indicator of bioremediation potential would be the relative population of heterotrophic bacteria of the site, particularly the subpopulations of hydrocarbon degrading bacteria, which can use gasoline hydrocarbons as their sole carbon and energy source. Bacteria populations are enumerated on agar plates as colonies that grow up over a 7-day period (14 days for anaerobes) from 10-fold serial dilutions of the groundwater. Statistically, every dispersed living bacterium should give rise to at least one bacterial colony (sometimes two or more organisms yield a single visible colony), so the data is expressed in terms of colony forming units.

When hydrocarbon concentrations are low ($< 1\text{mg/l}$), aerobic hydrocarbon-degrading bacteria populations will also appear low, indicating site conditions that have remained anaerobic for a



considerable time. When background populations of total heterotrophs are about an order of magnitude higher than specific degraders, (100-400 cfu/ml), a viable aerobic (more likely, facultative) bacteria are present but only a small percentage of them are capable of using the petroleum hydrocarbon contamination as their sole carbon source.

The bacterial population data further indicate the contaminated groundwater is not able to support aerobic biodegradation of the residual hydrocarbons without the introduction of higher oxygen concentrations. Anaerobic bacteria populations were not measured. Once populations of relevant bacteria strains have been documented, the next most important parameter to evaluate is dissolved oxygen.

Heterotrophic Plate Count is used to determine the number of microbial units within the liquid or soil sample. The result is calculated in Colony Forming Units. It is an excellent way to show that biodegradation is occurring. Total heterotrophs range from 3×10^4 to 8×10^5 cfu/ml in MW-9, MW-1A and MW-7, respectively. Adequate conditions exist for microbial growth.

Specific Hydrocarbon Degraders indicate the colony forming units of the microbes that specifically target the gasoline/diesel as a food source. The specific degraders ranged from $< 1 \times 10^1$ for MW-7 and up to 6×10^2 cfu/ml for MW-1A, which also has the highest hydrocarbon concentration. Once oxygen is added on site, increases in specific degraders and total heterotrophs should be observed above the background levels noted above.

CHEMICAL DATA

Dissolved oxygen (DO) identifies aerobic and anaerobic regions of contaminated site and the chemical, physical and biochemical activities occurring. A low dissolved oxygen level can limit the bacterial metabolism of certain organic compounds. Without adequate oxygen (e.g., at least 2-3 parts per million), the rates of aerobic biodegradation would be inhibited and the TPH contaminant concentrations would remain in equilibrium with the desorption of petroleum hydrocarbons from contaminated soil in contact with the water.



The DO at the site is between 4.3 mg/l (MW-1A; within the core of the plume) to 4.4 and 4.3 mg/l (MW-7 and MW-9, respectively). MW-7 and MW-9 are in the downgradient direction, and are relatively clean wells. This measurement was performed on-site using a calibrated Point-Four Dissolved Oxygen meter. Unless there is infiltration of oxygen-rich surface waters, the current readings for DO are not believed to be accurate as confirmed by the nitrate concentrations. MW-1A is believed to be within an anaerobic environment as the nitrate has almost completely been consumed. The other two wells, MW-7 and MW-9 also show low levels of nitrate, probably related to the consumption of nitrate as a terminal electron acceptor. Nitrate is only consumed after all the oxygen has been consumed, as oxygen is preferentially used as a terminal electron acceptor when available. Rapid biodegradation of the petroleum hydrocarbons would require adequate oxygen levels to sustain continuous aerobic respiration for the oxidation of contaminants by naturally occurring bacteria. DO measurements can be problematic and difficult to correlate between field and laboratory equipment, between different DO meters in the same location and even between technicians.

Nitrate (NO₃) is an alternate electron acceptor used by various microbes after oxygen is consumed. At the Subject Property, all nitrate analyses is listed on the laboratory reports as “non-detect”. This means that there was never nitrate in the system or that the nitrate has been consumed as an alternate terminal electron acceptor by the microbes as the oxygen concentrations have decreased to below usable levels. Under anaerobic conditions, facultative bacteria will use nitrate or sulfate as other alternative terminal electron acceptors in the electron transport chain that leads to the production of ATP in the absence of oxygen. The nitrate on the site for MW-1A, MW-7 and MW-9 was 1.1, 4.4, and 3.6 mg/l, respectively. The higher concentrations of hydrocarbons were associated with the decreased (consumed) nitrate levels, with the upgradient wells (MW-7 and MW-9) having the highest levels of nitrate.

Sulfate (SO₄) is an alternate electron acceptor used by various microbes after oxygen, nitrate and iron/magnesium are consumed. The sulfate on the site for MW-1A, MW-7 and MW-9 was 42, 266 and 52 mg/l, respectively.



Nutrients such as nitrogen and phosphorus are essential to support microorganisms' growth under aerobic conditions and sustain biodegradation processes. Nutrients may be available in sufficient quantities in the aquifer, but more frequently, nutrients may need to be added to maintain adequate bacterial populations. A rough approximation of the maximum nutrient requirements can be based on the stoichiometry of the overall biodegradation process (U.S. E.P.A., 1995):

Carbon source + Nitrogen source + O₂ + Minerals + Nutrients →
Cell mass + CO₂ + H₂O + other metabolic by-products

The carbon source is the petroleum hydrocarbon. The most commonly accepted empirical formulas for bacterial cell mass are C₅H₇NO₂ and C₆₀H₈₇O₃₂N₁₂P. Using the empirical formulas for cell biomass, the carbon : nitrogen : phosphorus ratios necessary to enhance aerobic bioremediation range from 100 : 10 : 1 to 100 : 1 : 0.5.

If the nutrients become depleted during the in-situ remediation process, the addition of the nutrients into the subsurface is quite simple. Although phosphate tends to recycle within an ecosystem, nutrient depletion would inhibit biological activity if higher gasoline hydrocarbon concentrations were present (> 5,000 ug/L TPH-g).

MICROBIOLOGICAL STUDY – DISCUSSION

The concentrations of petroleum hydrocarbons as TPH-gasoline and TPH-diesel at the site are well within the optimum concentration range for effective enhanced in-situ bioremediation. In-situ groundwater bioremediation is effective at constituent concentrations of less than 50,000 mg/l for total petroleum hydrocarbons, less than 7,000 mg/l for chlorinated solvents and less than 2,500 mg/l for heavy metals. Concentrations higher than these levels make in-situ groundwater bioremediation ineffective as the environment is too toxic for microbial growth or conditions inhibit bacterial growth. Long remediation times are also likely at excessive concentrations. In addition to the maximum concentration that can be treated, cleanup requirements must be



evaluated. Bioremediation of petroleum hydrocarbons where the constituent concentration is greater than 0.1 mg/l and hydrocarbon reduction is up to 95% is effective and quite possible (U.S. E.P.A., 1995). Treating concentrations below 0.1 mg/l with a greater than 95% contaminant reduction is only potentially effective and pilot studies are required to demonstrate reductions.

Bioaugmentation is where microorganisms are added to the injected or infiltrated water to increase microbial activity. Bioaugmentation is generally not necessary as indigenous microbes, when given an optimized environment with proper oxygen levels and nutrients will perform well. Indigenous microbes are acclimated to the site-specific contaminants and conditions. Only in rare cases is bioaugmentation suggested.

Clearwater does not generally recommend bioaugmentation unless other approaches enhancements have been used first. Bioaugmentation is considered when the populations of microbes are below a threshold where success or survival is questionable. In this case, microorganisms are added to the groundwater to increase microbial activity. Bioaugmentation is generally not necessary, as indigenous microbes will perform well when given an optimized environment with proper oxygen levels and nutrients. Indigenous microbes are acclimated to the site-specific contaminants and conditions. The most common type of bioaugmentation would be the culturing of indigenous microbes in the laboratory that are then placed back into the same environment. This method only increases the numbers of acclimated indigenous microbes. Only in rare cases is bioaugmentation using specialized microbes suggested.

It is quite apparent that the biodegradation component of the natural attenuation process at this site has been hampered by unfavorable conditions in the aquifer. Based on the concentration history of the site, it appears that these conditions have existed for several years. In general, biodegradation stops or slows down due to a lack of dissolved oxygen for aerobic respiration and metabolism of the hydrocarbons or a depletion of essential nutrients. Other possible inhibitory factors could include very poor transmissivity (depresses mass transfer for active



biodegradation), lack of water in the most contaminated areas (for contaminated soils above the groundwater table) or the presence of inhibiting metals or other substances toxic to the bacteria. It is possible, although rare, that suitable populations of hydrocarbon-degrading bacteria have not evolved or acclimated at this site to degrade the petroleum fractions. The most likely causes for such low biodegradation activity are low oxygen levels and depleted nutrients.



6.0 DELIVERY OF DISSOLVED OXYGEN

Presently there are a variety of technologies available which will introduce low to moderate concentrations (10-20 ppm) of stable dissolved oxygen into ground water. Once this elevated dissolved oxygen mixes with gasoline-contaminated ground water, natural biodegradation occurs and aerobic microorganisms consume the gasoline constituents. Dissolved gasoline constituents in ground water can be treated by mechanical technologies such as pump and treat systems or air sparging. These technologies are for the most part initially effective, but they can be both expensive and time consuming to operate until site closure is achieved. Sparging or bubbling air or oxygen into an aquifer will not create high dissolved oxygen concentrations. In fact, sparging has been shown in some cases to enhance the volatilization and migration of the volatile contaminants from the saturated zone into the vadose zone. Effectiveness of air sparging is highly site-specific and un-predictable.

Enhanced bioremediation by the use of injected dissolved oxygen has been proven to be an effective technology to reduce both BTEX and MTBE. However many ground water environments that are high in ferrous iron and BOD, for example, will consume large volumes of injected dissolved oxygen before aerobic bacteria can utilize the oxygen as part of the process of consuming BTEX and MTBE. Therefore the efficient delivery of dissolved oxygen into ground water is essential to insure that an abundance of oxygen will remain for the bioremediation of hydrocarbons.

Dissolved oxygen can be added to the groundwater using several technologies. Oxygen movement in the groundwater will be mainly through diffusion. Since enhanced bioremediation is a slow process (3 to 5 years), several oxygen systems were evaluated below:

6.1 Option 1 - Air Sparge system

This system would use an active blower to add oxygen to the subsurface at about 10- 12 mg/l. Air sparging systems generate excess bubbles of oxygen. This excess oxygen volatilizes the contaminants in the saturated zone and transports them into the vadose zone. Air sparge systems



work best with soil vapor extraction systems, so that any contaminants moved into the vadose zone, can be removed by the SVE system. Since diffusion of the oxygen moves based on Fick's Second Law of Diffusion, the levels of 10-12 mg/l oxygen would have a radius of influence on this site of about 3 to 4 feet from the injection wells. For 100 lbs. of oxygen, 4 wells would require 4 years to operate. This is an active treatment system, which requires electricity and has moving parts.

Cost Analysis

This option requires equipment (\$18,000), design, permitting, and supervision (\$15,000), and installation (\$10,000) for the installation of 100 lbs. of oxygen. The operations and maintenance of an active system is time and energy consuming. Given the monthly or bi-monthly visits, electricity bills, it is estimated that the cost for operations and maintenance as well as project management will be about \$1,500 per month for four years. For a four-year project, the operations and maintenance would be \$72,000. The installation of 4 new wells at \$1,500 per well (\$6,000) and the use of existing wells for air sparge equipment will be required. If existing wells were used, \$6,000 could be saved. The total cost would be \$121,000 plus groundwater monitoring (\$25,000/year)

6.2 Option 2 – Oxygen Release Compound (ORC)

Magnesium peroxide (MgO_2), under the brand name of Oxygen Release Compound (ORC) from Regenesis (www.regenesis.com) provides oxygen by slowly releasing oxygen as the magnesium peroxide reacts with water, it forms magnesium hydroxide ($\text{Mg}(\text{OH})_2$), liberating oxygen (O_2) in the process. The ORC is either placed into wells as "socks", a mixture of ORC product and sand, or injected under pressure through Geoprobe rods. The ORC slurry reacts over time. Duration of the reaction is estimated to be about 3 to 6 months. Several injections are required. ORC socks provide about 2 to 4 mg/l oxygen in the wells. Radius of influence is estimated to be about 2 to 4 feet from the well or well point. According to the manufacturer's information, about 18% of their sites remediate successfully, and the remaining sites require multiple injections or do not remediate. Clearwater has had experiences with sites that did not successfully remediate using



this product, even after multiple applications. The advantage to this approach is that it is completely passive.

Cost Analysis

This option requires ORC materials (\$60,000), design, permitting, and supervision (\$15,000), and installation of 5 events (\$20,000) for the installation of 100 lbs. of oxygen. It is estimated that the cost for operations and maintenance will be zero, but project management will be about \$500 per month for 6 years. For a six-year project, the operations and maintenance would be \$36,000. The total cost would be \$131,000 plus groundwater monitoring (\$25,000/year)

6.3 Option 3 – PermeOx

Calcium peroxide (CaO_2), under the brand name of PermeOx from FMC, marketed by Panther Technologies, (http://www.panthertech.com/PDF/PermeOx_Plus_Price_Sheet.pdf) provides oxygen by slowly releasing oxygen as the calcium peroxide reacts with water, it forms calcium hydroxide ($\text{Ca}(\text{OH})_2$), liberating oxygen (O_2) in the process. The PermeOx is injected under pressure through Geoprobe rods. The slurry reacts over time. Duration of the reaction is estimated to be about 3 to 6 months. Several injections are required. PermeOx provides about 6 to 8 mg/l oxygen in the wells. Radius of influence is estimated to be about 4 to 6 feet from the well or well point. The advantage to this approach is that it is completely passive.

Cost Analysis

This option requires PermeOx materials (\$60,000), design, permitting, and supervision (\$15,000), and installation of 5 events (\$20,000) for the installation of 100 lbs. of oxygen. It is estimated that the cost for operations and maintenance will be zero, but project management will be about \$500 per month for 4 years. For a six-year project, the operations and maintenance would be \$24,000. The total cost would be \$79,000 plus groundwater monitoring (\$25,000/year)



6.4 Option 4 – iSOC Oxygen Mass Transfer Tool

The iSOC oxygen diffusion tools are designed as a 96% efficient gas to liquid mass transfer tool. The iSOC probe is installed in normal 2-inch diameter wells. The iSOCs system works with industrial-grade oxygen tanks connected through 1/4" diameter tubing so that 100% oxygen is fed down the well into the iSOC diffusion tool. The hollow fiber membrane diffuses the oxygen on a molecular basis into the groundwater. The iSOC tool is made by inVentures Technologies, Inc. (www.gasinfusion.com). With 5, 10 and 15 feet of water column in a well, the dissolved oxygen could be as high as 42, 55 and 62 mg/l. Actual case studies with 5 to 10 feet of water commonly show 30 to 50 mg/l of dissolved oxygen. At 10 to 15 cc/minute, one 250 cubic foot oxygen cylinder can supply a well at 0.77 cubic feet per day for a period of almost one year. There are no moving parts or electricity requirements for the iSOC system, making it virtually passive.

Cost Analysis

This option requires equipment (\$24,000), design, permitting, and supervision (\$15,000), and installation (\$4,000) for the installation of 100 lbs. of oxygen. It is estimated that the cost for operations and maintenance as well as project management will be about \$1,000 per month for one year for the installation. For the theoretical one-year project (100 lbs. of oxygen), the operations and maintenance would be \$12,000. Four wells would be required at \$1,500 per new well (\$6,000) for 100 lbs. of oxygen. If existing wells were used, \$6,000 could be saved. The total cost would be \$61,000 plus groundwater monitoring (\$25,000/year)

SUMMARY OF REMEDIAL OPTIONS FOR ENHANCED BIOREMEDIATION

Since the complete vertical and lateral delineation of the contaminants has not been accomplished yet, the cost for remediation is based on installing 100 lbs. of dissolved oxygen into the groundwater. Diffusion by all these oxygen delivery systems is based on Fick's First and Second Laws of Diffusion. Molecular diffusion is the process by which both ionic and molecular species (dissolved oxygen in this case) move from areas of higher concentration to areas of lower concentration. Diffusion is a slow but ongoing process.

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Oxygen Delivery System	Maximum Amount of Oxygen in Well	Original Cost of product/equipment plus electrical, operations and maintenance	Number of years to place 100 lbs of oxygen in a 4-well area
Option 1 Air Sparge system	10-12 mg/l	\$48,000 for equipment plus \$18,000 per year (O&M) for four years + \$6,000 for 4 wells = \$121,000 plus groundwater monitoring at \$25,000 per year.	4 years, 4 wells
Option 2 Oxygen Release Compound (ORC) injected into ground	2-4 mg/l released into well or into ground (injected as a plug)	ORC For 100 lbs. of oxygen = 4,000 lbs. X \$15/lb. + \$4,000 for each of 5 injection events = \$131,000 plus groundwater monitoring at \$25,000 per year.	6-8 years, or several ORC points
Option 3 PermeOX Compound injected into ground	6-8 mg/l released into well or into ground (injected as a plug)	PermeOX For 100 lbs. of oxygen = 2,000 lbs. X \$10/lb. X \$4,000 for each of 5 injection events = \$79,000/100 lbs. plus groundwater monitoring at \$25,000 per year.	4 years or several well points
Option 4 iSOC mass transfer device	35- 50 mg/l for 5 to 10 feet of water column	4 iSOCs \$6,000 X 4 = \$24,000 + \$6,000 for wells plus \$1,000/month maintenance for one year = \$61,000 plus groundwater monitoring at \$25,000 per year.	1 year; 4 wells



7.0 RECOMMENDATIONS ON OXYGEN DELIVERY SYSTEM

Based on the evaluation of low permeability sediments in the aquifer materials, Clearwater recommends the iSOC oxygen diffusion system for enhanced bioremediation. Enhanced bioremediation is a slow process. Although it may take a longer period of time for remediation to reach acceptable levels for site close, Clearwater recommends budgeting 3 to 5 years for enhanced bioremediation to occur. For that period of time, more oxygen will get into the subsurface and out into the formation using the iSOC system, than any of the other options listed above. Therefore the price per pound of oxygen will be least with the iSOC system and the concentration will be highest with this system. Remediation of the hydrocarbon-impacted groundwater will be accomplished by using a gas infusion technology. The following is a summary of the proposed oxygen delivery system:

7.1 Oxygen Infusion – iSOC System

High DO levels have been related to increased rates of petroleum hydrocarbons, BTEX, MTBE, TBA and total VOC degradation. Oxygen infuser - iSOC is a technology that uses proprietary diffusion equipment to enrich the dissolved oxygen (DO) content of groundwater without causing aeration and volatilization of organic compounds. The diffusion tools consist of a chamber containing micro-porous polymeric hollow fibers with micron size holes that create a large surface area for oxygen dispersion. The diffusion tools are suspended down-hole in standard two-inch or larger diameter wells. The tools are connected to industrial grade oxygen cylinders located in the secured treatment compound. Elevated levels of dissolved oxygen can be achieved in the range of 40 to 80 milligrams per liter (mg/L), depending on the thickness of the water column in the well. The numbers are based on Henry's law of gas solubilities.

The iSOC tools are connected with ¼" diameter polyurethane tubing to a 2-stage, low flow oxygen regulator and the 281 cubic foot industrial grade oxygen tank. Installation is performed using a 2' X 2' watertight well box for individual locations. For wells where there is one large secured supply of oxygen tanks in a secured cage, the polyurethane tubing is placed in a 1"



by 1" concrete channel cut into the concrete with a walk-behind saw. The base of the channel is usually lined with fine sand and the tubing is run to the wells. The channel and tubing is covered with mortar mix and smoothed out, protecting the oxygen delivery tubing. This method is passive after installation. Radius of influence (ROI) is about 10 feet in clay-rich soil. The ROI will be circular in shape, centered on the wells. The system does not require external power.

The predicted DO concentrations under various lengths of water column are listed below:

	Water Columns (inches)				
Gas Type	5	10	15	20	50
Aerobic gas:					
Oxygen	42	55	62	69	111
Anaerobic gases:					
Propane	66	88	99	110	175
Hydrogen	2	2	3	3	5
Methane	22	30	33	37	59
Ethane	57	75	85	95	150

Gas infusion technology works in both high and low permeability sites. Sites dominated by silts and clays may take considerably more time to see results due to the low groundwater flow velocities. In addition, typically high carbon and organic content of silts and clays may provide large oxygen demand. This technology works well in the presence of dissolved phase concentrations of total VOC and MTBE; however, enhanced bioremediation does not work well in the presence of liquid phase hydrocarbons (LPH).

Based on the manufacturer recommendations, the system should operate at an oxygen flow rate of 15 cc per minute or 0.77 cubic feet per day per well. The miniaturized built-in iSOC regulators keep the diffusion gas pressure at about 2 to 5 per square inch (psi) above the



8.0 CORRECTIVE ACTION PLAN ADDENDUM ACTIVITIES

Task 1 – Corrective Action Plan Addendum (This report)

Clearwater prepared this Corrective Action Plan Addendum as part of Task 1.

Task 2 – Interim Remedial Investigation

Clearwater will perform an Interim Remedial Investigation to more adequately address vertical and lateral extent of the contamination. Most of the information from previous lithologic logs from borings and well installations is limited to soil samples collected every five feet using a hollow-stem auger rig. When planning an in-situ remedial effort, detailed and continuous lithologic descriptions are needed for design purposes. The current number of wells on site also limits the understanding of the full vertical and lateral extent of the contamination.

Clearwater will drill nine soil borings; B-10-05 to B-18-05, continuously cored to about 25 feet below ground surface using a direct push rig. Continuous lithologic cores will be collected for accurate subsurface information. Soil samples will be collected for lithologic description and possible laboratory analysis. Selected soil samples will be screened for organic vapor analysis using a Thermo 590B photoionization detector (PID) or equivalent unit. A temporary well casing will be installed in selected boring locations for laboratory analysis. If significant lithologic information is lost in the saturated zone due to poor soil sample recovery, Geoprobe resistivity logging will only be performed in the area of selected boreholes for verification of lithologic characteristics. The resistivity logs and data will be used during cross section preparation.

Three of these borings (B-10-05 to B-12-05) will over-drilled using a hollow stem auger rig and converted to monitoring wells MW-10 to MW-12. The proposed monitoring wells will be installed in the borehole by overdrilling the locations with a hollow stem auger rig and installing two-inch diameter wells according to the Clearwater Group standard procedures included in Appendix C. Several detailed cross-sections will be prepared from the lithologic information from the new wells and the previously collected data.



maximum static water pressure. This pressure is required so the air chamber within the diffusion tool does not flood.

Just prior to iSOC system implementation, a baseline documentation of indirect geochemical indicators for enhanced bioremediation will be performed. The baseline study will occur during a regularly scheduled quarterly groundwater sampling event. The samples will be collected from three wells (MW-1A, EW-1, MW-2A) within the plume, one well (MW-9) downgradient and one well (MW-6 or MW-13) upgradient or cross gradient. Field tests for indirect geochemical indicators include pH, dissolved oxygen (DO), oxygen-reduction potential (ORP), temperature, and conductivity. In addition, total iron and ferrous iron (Fe^{+2}) (reduced) will be measured using Hach colorimetric field kits. Ferric iron (Fe^{+3}) (oxidized) will be determined by subtracting the ferrous iron result from the total iron. These indirect indicators will be measured every quarter during the quarterly monitoring events. This level of indirect geochemical indicator sampling is not recommended more than every 9 or 12 months after system installation.



Task 3 – Collect Indirect Geochemical Indicators for Background Levels

Clearwater will collect enhanced bioremediation information just prior to iSOC system installation by performing a baseline sampling event (during a regular quarterly groundwater sampling event). The samples will be collected using three wells (MW-1A, EW-1, MW-2A) within the plume, one well (MW-9) downgradient and one well (MW-6 or MW-13) upgradient or cross gradient. Enhanced bioremediation samples will be analyzed for the contaminants of concern, as well as nitrate and sulfate, macronutrients: orthophosphate-phosphate and ammonia as nitrogen. Oxygen demand in the groundwater samples will be determined by the five-day biological oxygen demand (BOD₅) and chemical oxygen demand (COD) and solid oxygen demand (SOD). Total inorganic carbon will also be evaluated. Additional analyses include total organic carbon, total dissolved solids, and alkalinity (speciated). Total heterotrophic count and specific hydrocarbon degraders will be performed. A summary of analytical is shown below:

<u>Direct Indicator</u>	<u>Analyses</u>
Contaminant	TPHg, BTEX, MTBE, TBA, etc.
<u>Indirect Indicators</u>	<u>Analyses</u>
Microbial Activity	Total Heterotrophic Plate Count Specific Hydrocarbon Degraders
Macronutrients	Ammonia as nitrogen Ortho-phosphate
Terminal Electron Acceptors	Oxygen, measured as dissolved oxygen (DO) in field Nitrate (lab analysis) Ferrous iron (Fe ⁺²) and Total iron (field kits) Sulfate (lab analysis)
Total Oxygen Demand	Solid or sediment oxygen demand (SOD, lab) Water oxygen demand: Chemical Oxygen Demand (COD, lab) Biological Oxygen Demand (BOD ₅ , lab)
REDOX, Field Parameters	Dissolved Oxygen (DO) (downhole meter) Oxidation-Reduction Potential (ORP) (downhole meter) Temperature, pH, conductivity (field meter)



Carbon Status	Total organic carbon (TOC, lab) Total inorganic carbon (TIC, lab) Speciated Alkalinity (lab)
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Other Analyses	Total dissolved solids (TDS, lab)
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Bench testing is generally not performed for routine aerobic bioremediation projects, unless specific site conditions require it. Bottle types for each analysis is listed below:

<u>ANALYSES</u>	<u>BOTTLE TYPE</u>
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BIOLOGICAL ANALYSES:

Heterotrophic Count	
Specific Degradors	1 Liter HDPE

CHEMICAL ANALYSES:

pH, Speciated Alkalinity, o-Phosphate, Nitrate, Sulfate	1 Liter HDPE
Total Dissolved Solids (TDS)	1 Liter HDPE
Total Inorganic Carbon (TIC)	125 ml Amber Glass, HCl
Total Organic Carbon (TOC)	125 ml Amber Glass, HCl
Ammonia as nitrogen	1 Liter Amber
Dissolved CO ₂	please call
Biological Oxygen Demand (BOD)	1 Liter HDPE*
Chemical Oxygen Demand (COD)	250 ml Amber Glass, H ₂ SO ₄
Ferrous Iron (Fe ²⁺) Reduced Form: field)	125 ML HDPE, HCl (see field)

HDPE = high density polyethylene

Field Tests:

Dissolved oxygen (DO), pH, temp,
Oxidation-Reduction Potential (ORP),
Ferrous Iron (Fe²⁺) Reduced Form,
Total Iron,
Temperature, pH, conductivity

Calculations:

(Fe³⁺) Oxidized Form,
Dissolved carbon dioxide (CO₂)



- A separate 1-liter container is needed for BOD so there is sufficient volume to do all the additional tests with just one liter. Also, BOD needs to be measured from a container with minimal or no headspace.

Tasks 4, 5, and 6 (Future Activities)

After the above tasks are completed, Clearwater will prepare a report of the findings with subsurface cross sections, which will be part of the Remedial Action Plan (RAP) (Task 4). With the new data (Tasks 2 and 3), Clearwater will present the specific remedial action with details of installation, cost, and schedules. After the RAP is approved, Clearwater will install the selected remedial system (Task 5) and conduct performance monitoring and operations and maintenance (O&M) on the remedial system until site closure can be obtained. Groundwater monitoring will also continue (Task 6).



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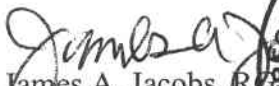
10.0 CERTIFICATION

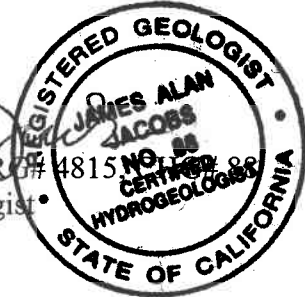
This report was prepared under the supervision of a professional State of California Registered Geologist at Clearwater Group. All statements, conclusions and recommendations are based solely upon published results from previous consultants, field observations by Clearwater Group and laboratory analysis performed by a California DHS-certified laboratory related to the work performed by Clearwater Group.

Information and interpretation presented herein are for the sole use of the client and regulating agency. A third party should not rely upon the information and interpretation contained in this document.

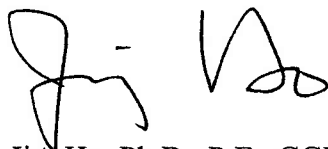
The service performed by Clearwater Group has been conducted in a manner consistent with the level of care and skill ordinarily exercised by members of our profession currently practicing under similar conditions in the area of the site. No other warranty, expressed or implied, is made.

Prepared by:

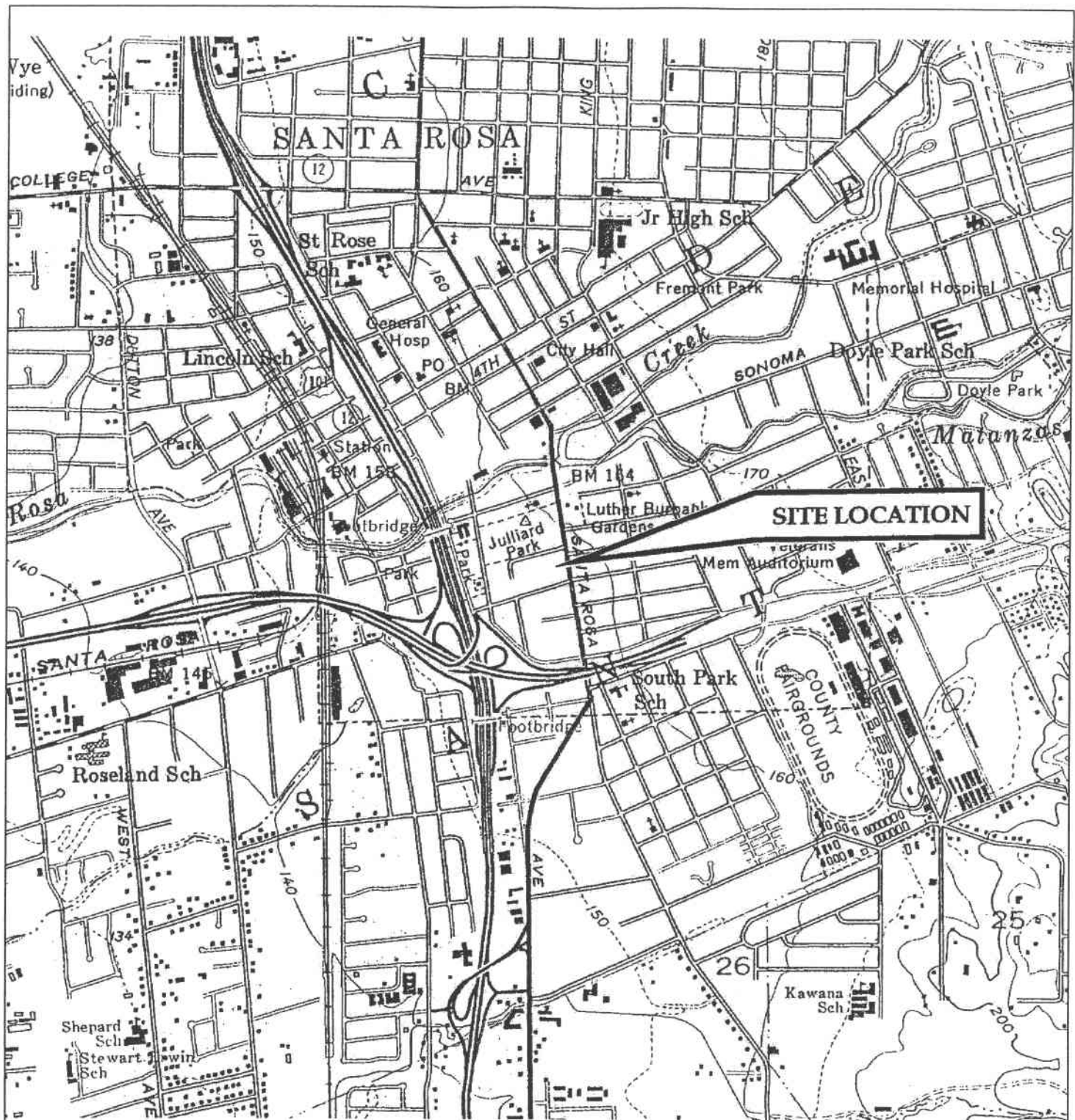

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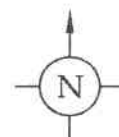
Reviewed by:


Jim Ho, Ph.D., P.E., CGWP
Principal Engineer

FIGURES



NOT TO SCALE



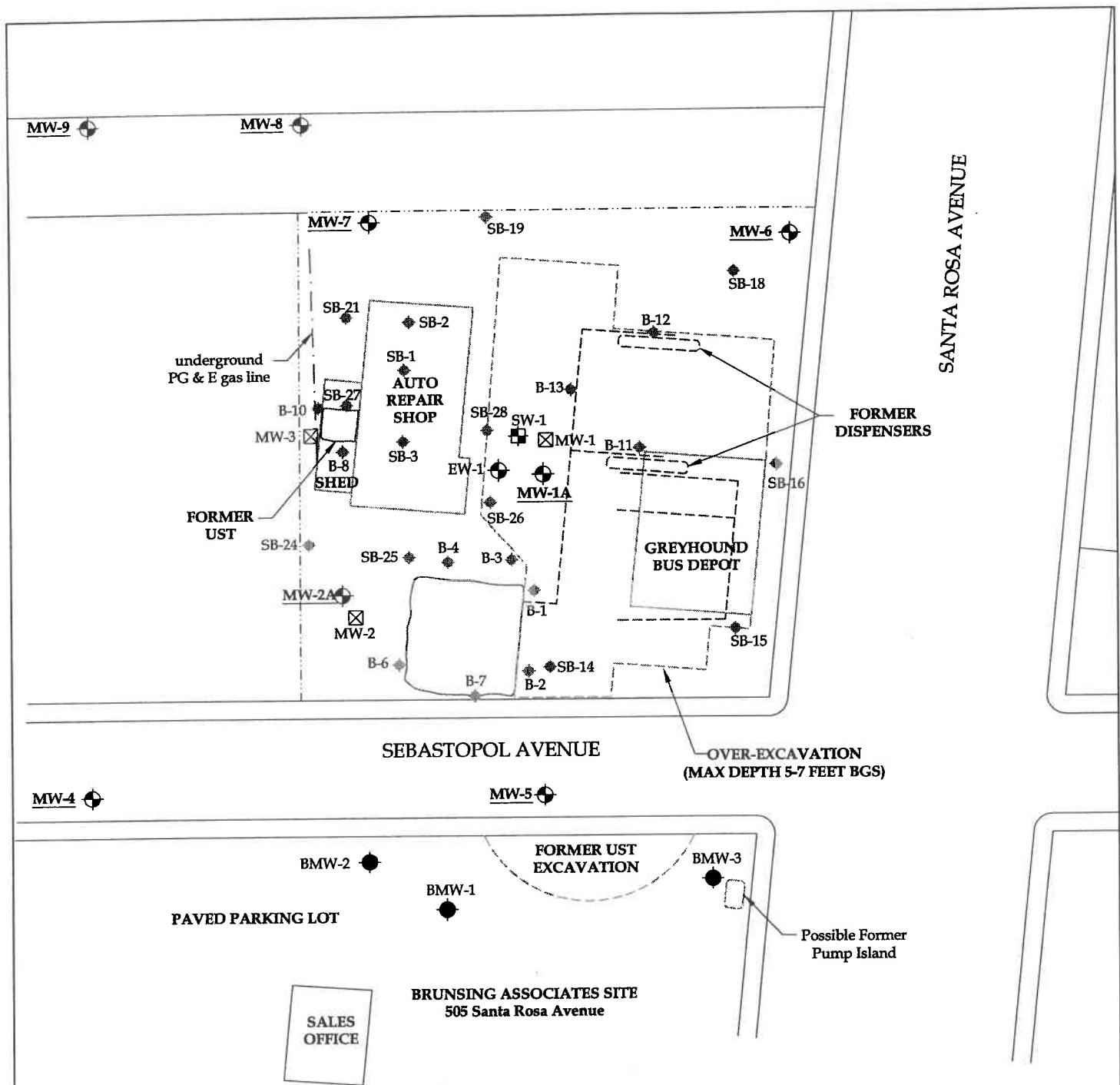
SITE LOCATION MAP
421 Santa Rosa Avenue
Santa Rosa, California

CLEARWATER GROUP






Project No.
AB021E

Figure Date
02/05

Figure
1



LEGEND

- MW-1  MONITORING WELL
- BMW-1  BRUNSING ASSOCIATES MONITORING WELL
- MW-3  DESTROYED/UNRECOVERABLE MONITORING WELL
- B-7  SOIL BORING IN LIEU OF UST EXCAVATION SAMPLING BY HLA
- SB-25  SOIL BORING/HYDROPUNCH BY GPI

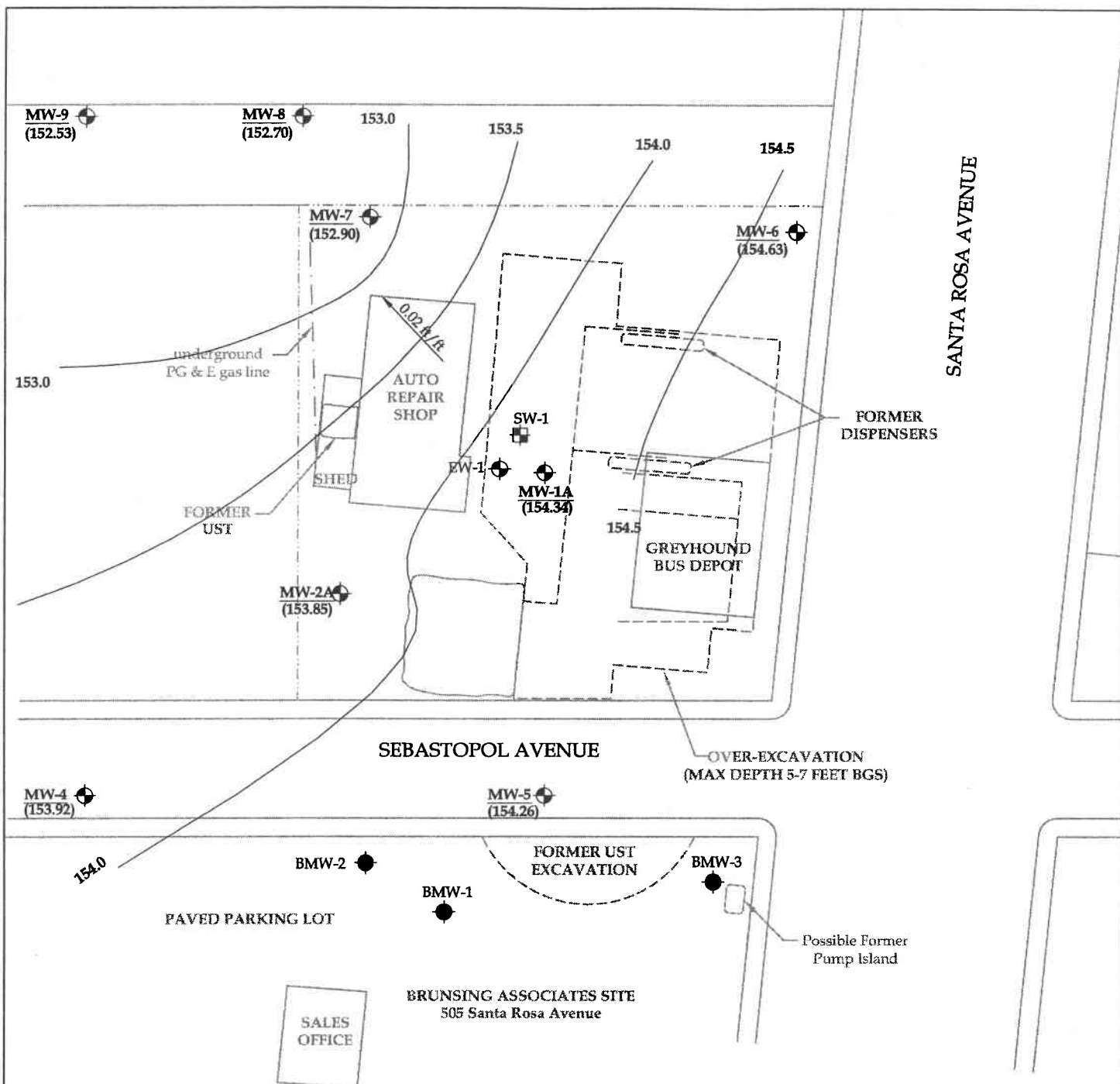
SITE PLAN
421 Santa Rosa Avenue
Santa Rosa, California

CLEARWATER GROUP

Project No.
AB021E

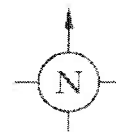
Figure Date
02/05

Figure
2



LEGEND

- MW-1** MONITORING WELL
- BMW-1** BRUNSG ASSOCIATES MONITORING WELL
- 152.00'** GROUNDWATER ELEVATION CONTOUR (HEIGHT IN FEET ABOVE MSL)
- 0.02 ft/ft** APPROX. GROUNDWATER FLOW DIRECTION & GRADIENT
- (152.00)** GROUNDWATER ELEVATION IN FEET ABOVE MSL

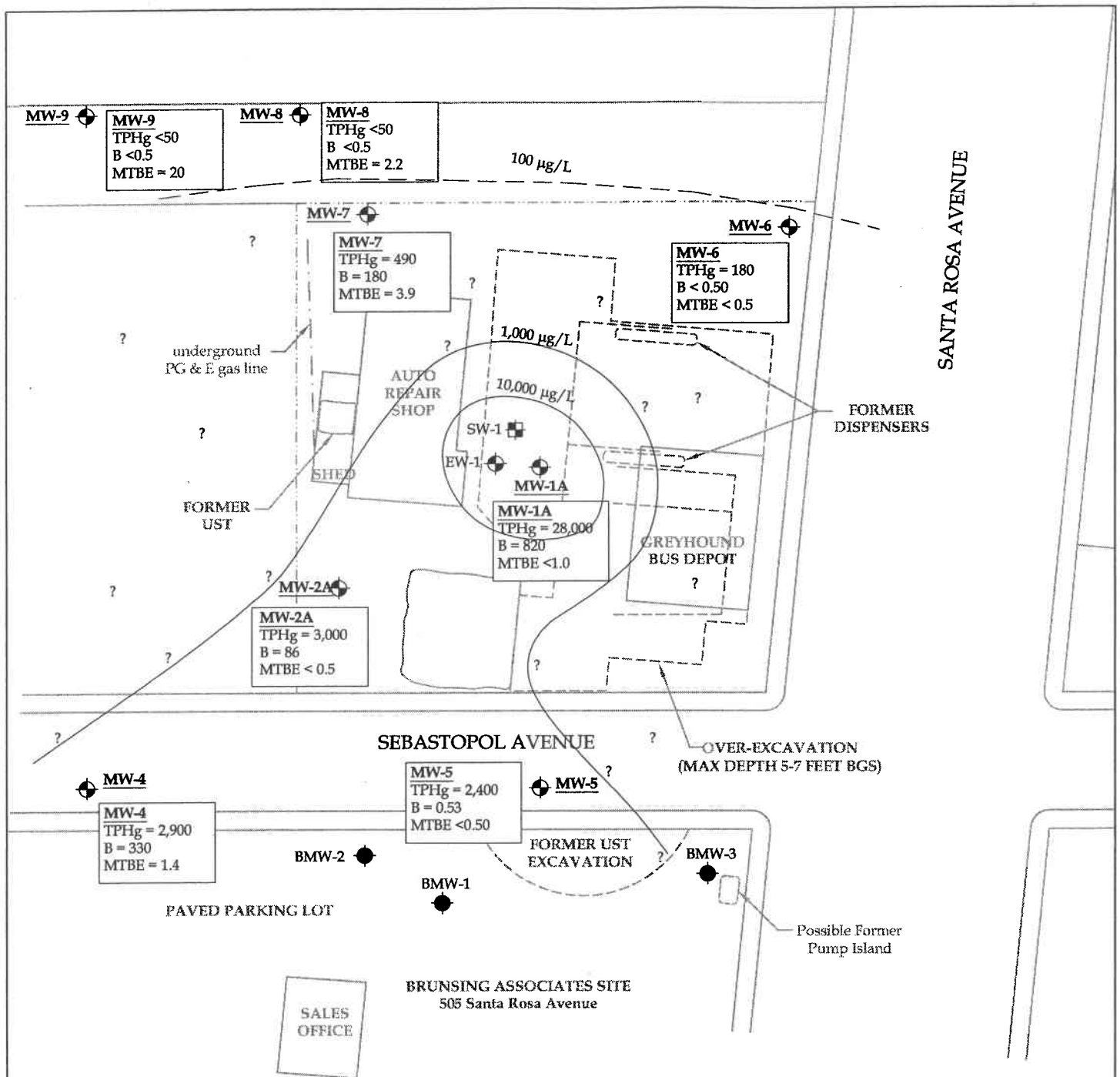


GROUNDWATER ELEVATION MAP January 13, 2005

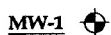
421 Santa Rosa Avenue
Santa Rosa, California

CLEARWATER GROUP

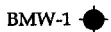
Project No. AB021E	Figure Date 1/31/05	Figure 3
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LEGEND



MONITORING WELL



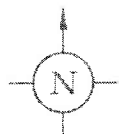
BRUNSGING ASSOCIATES MONITORING WELL

BEN. = 10 µg/L

BENZENE ISO-CONCENTRATION CONTOUR

MW-1
TPHg = 21,000
B = 1,600
MTBE = 14

CONCENTRATIONS OF: TOTAL PARTS HYDROCARBONS AS GASOLINE (TPHg), BENZENE (B), AND METHYL TERT-BUTYL ETHER (MTBE). ALL CONCENTRATIONS REPORTED IN MICROGRAMS PER LITER (µg/L)



TPH-g DISTRIBUTION MAP January 13, 2005

421 Santa Rosa Avenue
Santa Rosa, California

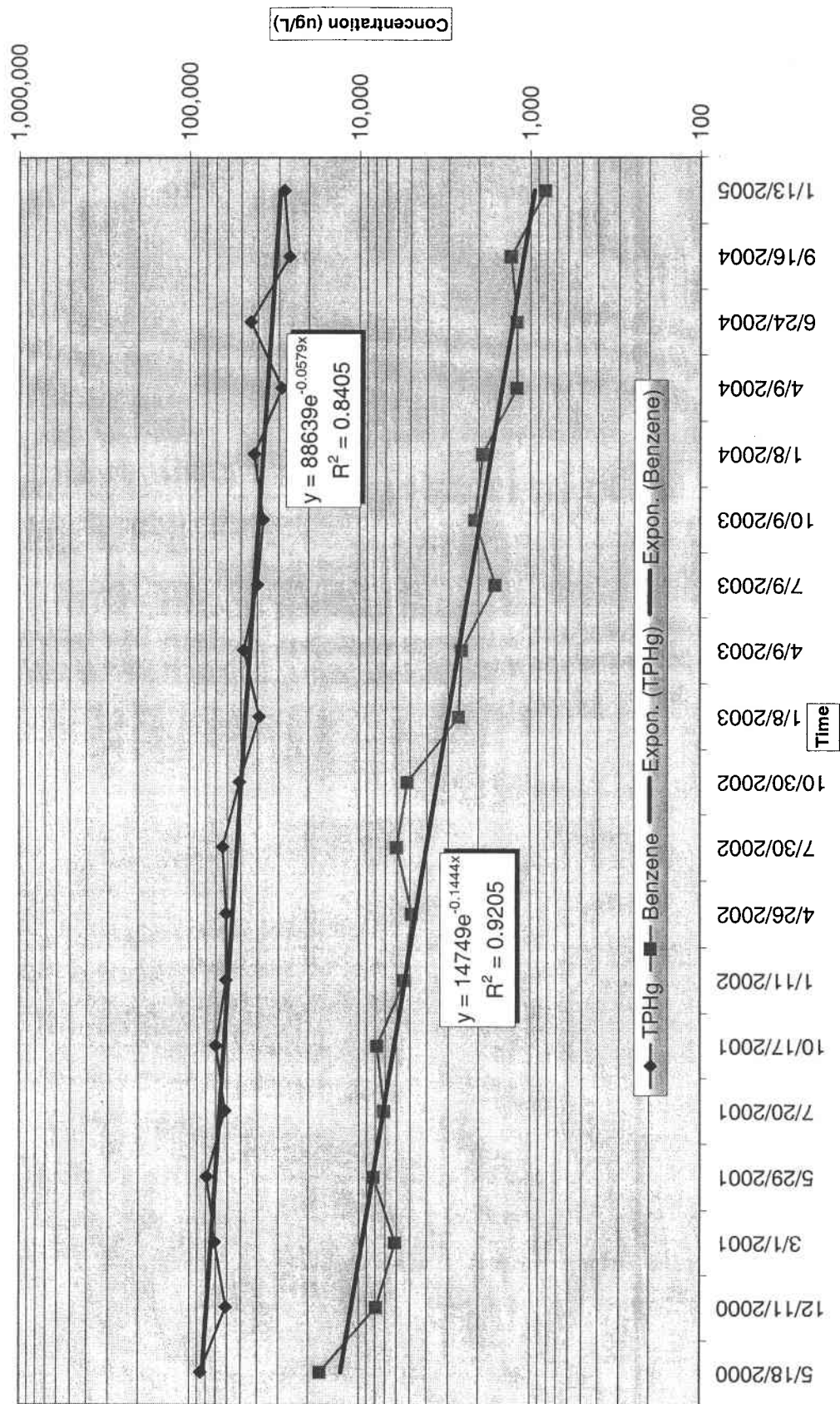
CLEARWATER GROUP

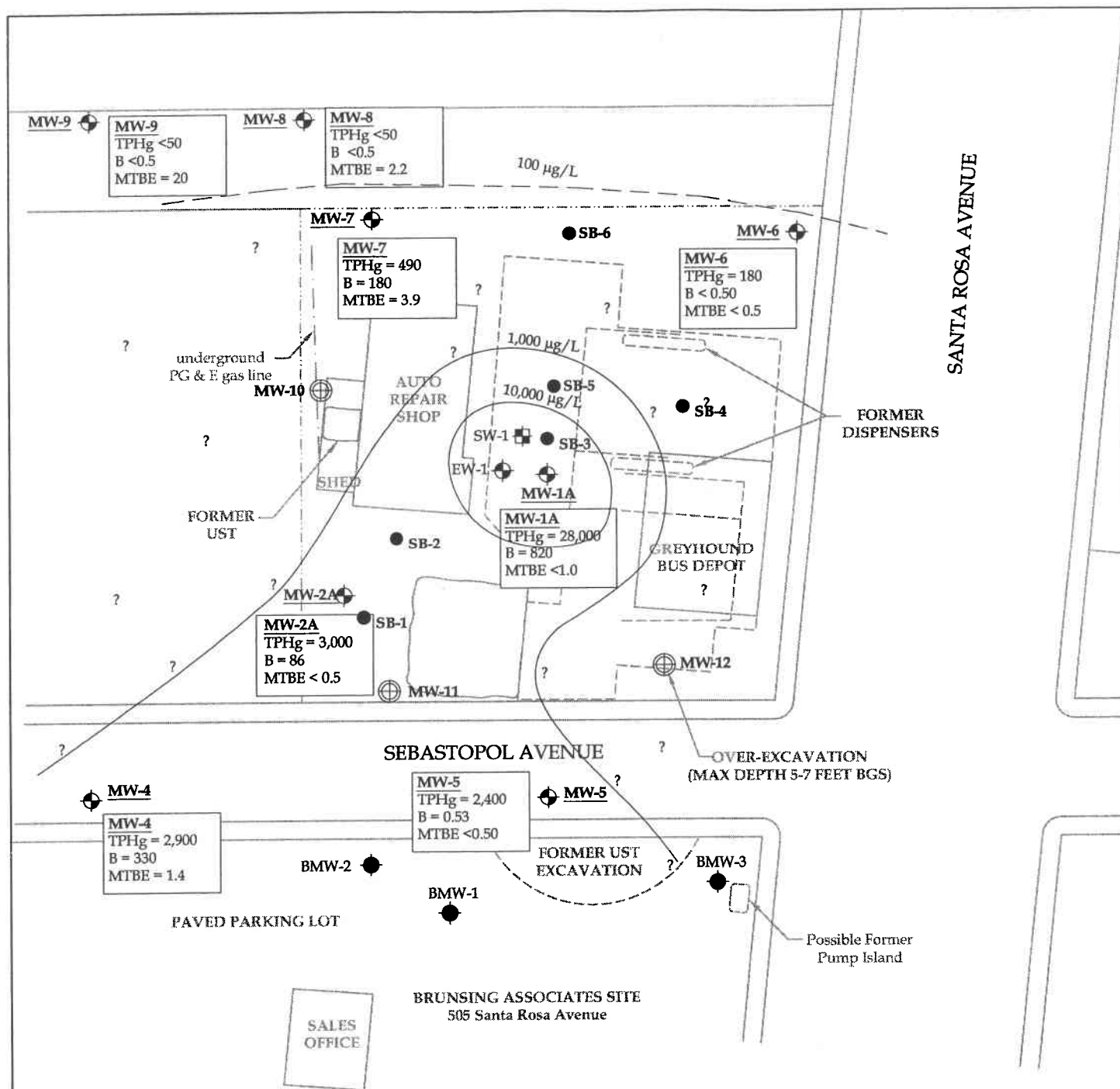
Project No.
AB021E

Figure Date
1/31/05

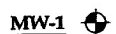
Figure
4

Figure 5
Empirical Evaluation of First Order Degradation Rates
MW-1A: TPHg/Benzene vs. Time
 421 Santa Rosa Avenue, Santa Rosa, CA

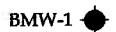




LEGEND



MONITORING WELL



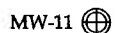
BRUNSGING ASSOCIATES MONITORING WELL

BEN. = 10 µg/L

BENZENE ISO-CONCENTRATION CONTOUR

MW-1
TPH_g = 21,000
B = 1,600
MTBE = 14

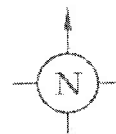
CONCENTRATIONS OF: TOTAL PARTS HYDROCARBONS AS GASOLINE (TPH_g), BENZENE (B), AND METHYL TERT-BUTYL ETHER (MTBE). ALL CONCENTRATIONS REPORTED IN MICROGRAMS PER LITER (µg/L)



PROPOSED MONITORING WELL



PROPOSED SOIL BORING



APPROXIMATE SCALE IN FEET

Proposed Well Installation and Soil Borings

421 Santa Rosa Avenue
Santa Rosa, California

CLEARWATER GROUP

Project No.
AB021E

Figure Date
2/05

Figure
6

APPENDIX A

Collected Data for 1st Quarter 2005 Monitoring:

Well Construction Data

Groundwater Elevations and Analytical Data

Microbiological Study Table (6/24/04)

Table 1
WELL CONSTRUCTION DATA
 421 Santa Rosa Avenue
 Santa Rosa, California
 Clearwater Group Project No. AB021C

Well I.D.	Date installed	Intstalled by	Casing diameter (inches)	Borehole diameter (inches)	Total depth (feet)	Screened Interval (feet)	Sand Interval (feet)	Slot Size (inches)	Sand Size
MW-1	12/13/1991 Destroyed 5/16/00	GPI	2	8	24	7 - 24	6 - 24	0.01	Monterey #2/12
MW-2	12/13/1991 Destroyed 5/16/00	GPI	2	8	25	7 - 25	6 - 25	0.01	Monterey #2/12
MW-3	12/16/1991 Could not be located / Unrecoverable following soil excavation remedial activities in 1996	GPI	2	8	22	7 - 22	6 - 22	0.01	Monterey #2/12
MW-1A	5/16/2000	Clearwater	2	8	20	5 - 20	4 - 20	0.02	Lonestar #3
MW-2A	5/16/2000	Clearwater	2	8	20	5 - 20	4 - 20	0.02	Lonestar #3
MW-4	5/17/2000	Clearwater	2	8	20	5 - 20	4 - 20	0.02	Lonestar #3
MW-5	5/17/2000	Clearwater	2	8	20	5 - 20	4 - 20	0.02	Lonestar #3
MW-6	5/16/2000	Clearwater	2	8	20	5 - 20	4 - 20	0.02	Lonestar #3
MW-7	5/16/2000	Clearwater	2	8	20	5 - 20	4 - 20	0.02	Lonestar #3
MW-8	12/5/2000	Clearwater	2	8	20	5 - 20	4 - 20	0.02	Lonestar #3
MW-9	12/5/2000	Clearwater	2	8	20	4 - 20	3.5 - 20	0.02	Lonestar #3

GPI = GeoPacific Investigations of Novato, California
 Clearwater = Clearwater Group of Point Richmond, California

Table 2
GROUNDWATER ELEVATIONS AND ANALYTICAL DATA

421 Santa Rosa Avenue
Santa Rosa, California
Clearwater Group Project No. AB021C

Well-No.	Date	TOC (feet)	DTW (feet)	GWE (feet)	LNAPL (feet)	O&G (μg/L)	TPHmo (μg/L)	TPHd (μg/L)	TPHg (μg/L)	Benzene (μg/L)	T (μg/L)	E (μg/L)	X (μg/L)	MTBE (μg/L)	ETBE, TBA, DIPE, TAME (μg/L)	1,2 DCA (μg/L)	EDB (μg/L)
MW-1	12/26/1991	159.42	13.70	145.76	0.05	170,000	<200	82,000 [^]	67,000	17,000	21,000	2,300	17,000	--	--	47	--
	3/28/1992	159.42	6.42	153.04	0.05	90,000	<200	3,000	120,000	35,000	27,000	1,200	2,100	--	--	110	--
	6/16/1992	159.42	10.02	149.42	0.03	<5,000	<200	12,000 [^]	62,000	15,000	8,100	1,800	8,300	--	--	52	--
	9/19/1992	159.42	13.16	146.36	0.13	<5,000	<200	11,000 [^]	390,000	27,000	19,000	3,600	18,000	--	--	<0.4	--
	12/13/1992	159.42	--	--	0.25	<5,000	<200	3,600 [^]	49,000	18,000	13,000	790	10,000	--	--	39	--
	9/7/1994	159.42	--	--	0.06	<5,000	<200	61,000 [^]	180,000	23,000	13,000	390	18,000	--	--	<0.4	--
	5/16/2000	Destroyed and replaced by MW-1A in adjacent borehole.															
MW-1A	5/18/2000	160.00	5.71	154.29	0.00	--	--	--	86,000	17,000	9,800	4,100	19,000	<250	--	--	--
	12/11/2000	160.00	10.30	149.70	0.00	--	--	--	61,000	7,900	2,900	3,400	14,000	<250 [†]	--	--	--
	3/1/2001	159.30	5.36	153.94	0.00	--	--	--	71,000	6,100	2,100	3,200	13,000	<20 to <200	--	<20	<20
	5/29/2001	159.30	8.69	150.61	0.00	--	--	--	79,000	8,200	3,000	3,300	13,000	<25	--	--	--
	7/20/2001	159.30	10.39	148.91	0.00	--	--	--	62,000	7,100	1,900	3,100	13,000	<25	--	<2.5	--
	10/17/2001	159.30	11.70	147.60	0.00	--	--	--	70,000	7,800	1,500	3,800	12,000	<25	--	<25	--
	1/11/2002	159.30	5.94	153.36	0.00	--	--	--	61,000	5,400	1,200	2,600	8,700	<20	--	<20	--
	4/26/2002	159.30	7.21	152.09	0.00	--	--	--	61,000	4,900	1,400	3,100	11,000	<20	--	<20	--
	7/30/2002	159.30	9.91	149.39	0.00	--	--	--	64,000	6,000	1,300	3,000	11,000	<10	--	--	--
	10/30/2002	159.30	11.16	148.14	0.00	--	--	--	51,000	5,200	420	3,400	5,200	<20	--	<2.5	--
	1/8/2003	159.30	5.32	153.98	0.00	--	--	--	39,000	2,600	600	2,100	6,600	2	--	<2.0	--
	4/9/2003	159.30	6.40	152.90	0.00	--	--	--	48,000	2,500	700	2,300	6,400	<1.5	--	<1.5	--
	7/9/2003	159.30	7.36	151.94	sheen	--	--	--	40,000	1,600	420	2,500	6,800	<1.0	--	<1.0	--
	10/9/2003	159.30	11.22	148.08	sheen	--	--	--	37,000	2,100	250	2,700	3,600	0.92	--	<0.50	--
	1/8/2004	159.30	5.00	154.30	sheen	--	--	--	42,000	1,900	410	2,200	5,600	<0.5	--	<0.5	--
	4/9/2004	159.30	6.62	152.68	0.00	--	--	--	29,000	1,200	280	1,600	4,200	<20	--	<20	--
	6/24/2004	159.30	10.05	149.25	0.00	--	--	--	44,000	1,200	210	2,200	3,600	<1.5	--	<1.5	--
MW-2	9/16/2004	159.30	12.77	146.53	0.00	--	--	--	26,000	1,300	130	1,800	2,400	0.76	TBA=12	<0.5	--
	1/13/2005	159.30	4.96	154.34	0.00	--	--	--	28,000	820	110	1,900	2,600	<1.0	--	<1.0	--
	12/26/1991	159.56	12.92	146.64	0.00	--	--	--	910	200	1.0	<0.50	32	--	--	--	--
	3/28/1992	159.56	5.28	154.28	0.00	--	--	--	38,000	6,500	350	1,500	1,800	--	--	--	--
	6/16/1992	159.56	9.05	150.51	0.00	--	--	--	15,000	3,000	250	1,300	1,300	--	--	--	--
	9/19/1992	159.56	12.21	147.35	0.00	--	--	--	8,700	1,100	34	340	140	--	--	--	--
	12/13/1992	159.56	--	--	0.00	--	--	--	4,500	1,400	190	490	750	--	--	--	--
MW-2A	9/7/1994	159.56	--	--	0.00	<5,000	<200	1,100 [^]	3,200	560	9.4	120	23	--	--	<0.40	--
	5/16/2000	Destroyed and replaced by MW-2A in adjacent borehole.															
	5/18/2000	159.54	6.17	153.37	0.00	--	--	--	4,200	86	<5.0	300	260	<50 [†]	--	--	--
	12/11/2000	159.54	11.14	148.40	0.00	--	--	--	2,700	110	11	94	91	<100 [†]	--	--	--
	3/1/2001	158.83	5.54	153.29	0.00	--	--	--	2,800	47	0.58	96	46	<0.50	<0.50 to <5.0	<0.50	<0.50
	5/29/2001	158.83	8.91	149.92	0.00	--	--	--	6,500	100	1.3	400	100	<0.50	--	--	--
	7/20/2001	158.83	10.61	148.22	0.00	--	--	--	9,100	190	3.0	800	320	<2.5	--	--	--
	10/17/2001	158.83	12.59	146.24	0.00	--	--	--	4,000	26	0.6	84	8	<0.50	--	--	--
	1/11/2002	158.83	4.51	154.32	0.00	--	--	--	100	9.6	<0.50	<0.50	<0.50	<0.50	--	--	--
	4/26/2002	158.83	9.21	149.62	0.00	--	--	--	7,100	160	2.3	1,000	85	<0.50	--	--	--

Table 2
GROUNDWATER ELEVATIONS AND ANALYTICAL DATA
421 Santa Rosa Avenue
Santa Rosa, California
Clearwater Group Project No. AB021C

Well-No.	Date	TOC (feet)	DTW (feet)	GWE (feet)	LNAPL (feet)	O&G (µg/L)	TPHmo (µg/L)	TPHd (µg/L)	TPHg (µg/L)	Benzene (µg/L)	T (µg/L)	E (µg/L)	X (µg/L)	MTBE (µg/L)	DIPE, TAME (µg/L)	1,2 DCA (µg/L)	EDB (µg/L)
MW-2A	7/30/2002	158.83	10.25	148.58	0.00	--	--	--	6,400	98	1.1	570	63	<0.50	--	--	--
	10/30/2002	158.83	12.31	146.52	0.00	--	--	--	2,700	46	<0.50	180	4.5	<0.50	--	--	--
	1/8/2003	158.83	5.04	153.79	0.00	--	--	--	5,000	240	<2.0	430	14.0	<2.0	--	--	--
	4/9/2003	158.83	6.40	152.43	0.00	--	--	--	8,400	170	<2.0	600	33	<2.0	--	--	--
	7/9/2003	158.83	8.48	150.35	0.00	--	--	--	8,400	150	<2.5	680	33	<2.5	--	--	--
	10/9/2003	158.83	11.66	147.17	sheen	--	--	--	4,500	95	0.82	250	8.1	<0.50	--	--	--
	1/8/2004	158.83	5.30	153.53	sheen	--	--	--	3,400	52	0.76	180	3.1	<0.50	--	--	--
	4/9/2004	158.83	6.63	152.20	0.00	--	--	--	3,600	49	0.64	210	4.4	<0.50	--	--	--
	6/24/2004	158.83	No Data	Vehicle Obstructed Access to Well	--	--	--	--	No Data - Vehicle Obstructed Access to Well	--	--	--	--	--	--	--	--
	9/16/2004	158.83	13.17	145.66	0.00	--	--	--	2,000	56	4.70	48	19.0	<0.50	ND	--	--
MW-3	1/13/2005	158.83	4.98	153.85	0.00	--	--	--	3,000	86	<0.50	190	1.7	<0.50	--	--	--
	12/26/1991	159.37	14.32	145.05	0.00	<5,000	<200	<50	<50	3.3	<0.50	<0.50	0.70	--	--	1.9	--
	3/28/1992	159.37	6.94	152.43	0.00	<5,000	<200	<50	<50	<0.50	<0.50	<0.50	<0.50	--	--	<0.40	--
	6/16/1992	159.37	10.82	148.55	0.00	<5,000	<200	160^	320	270	1.2	9.7	13	--	--	1.1	--
	9/19/1992	159.37	13.56	145.81	0.00	<5,000	<200	<50	1,100	1.9	<0.50	<0.50	<0.50	--	--	2.6	--
	12/13/1992	159.37	--	--	0.00	<5,000	<200	150^	140	43	<0.50	4.4	12	--	--	<0.40	--
	9/7/1994	159.37	--	--	0.00	<5,000	<200	110^	<50	<0.50	<0.50	<0.50	<0.50	--	--	<0.40	--
	5/16/2000	Well could not be located following construction activities, assumed to be buried.	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
	5/18/2000	157.63	4.50	153.13	0.00	--	--	--	36,000	4,600	1,100	1,800	6,900	<500†	--	--	--
	12/11/2000	157.63	9.08	148.55	0.00	--	--	--	17,000	3,500	280	600	1,600	<250†	--	--	--
MW-4	3/1/2001	156.91	3.24	153.67	0.00	--	--	--	19,000	2,400	370	640	2,100	<10	DIPE = 12	<10	<10
	5/29/2001	156.91	6.92	149.99	0.00	--	--	--	29,000	3,800	450	770	2,400	<20	--	--	--
	7/20/2001	156.91	8.79	148.12	0.00	--	--	--	13,000	3,000	88	230	300	1.9	--	--	--
	10/17/2001	156.91	10.56	146.35	0.00	--	--	--	13,000	3,300	68	280	240	<20	--	--	--
	1/11/2002	156.91	5.05	151.86	0.00	--	--	--	6,500	540	59	170	450	<2.0	--	--	--
	4/26/2002	156.91	5.03	151.88	0.00	--	--	--	14,000	1,400	200	450	1,000	0.95	--	--	--
	7/30/2002	156.91	8.26	148.65	0.00	--	--	--	16,000	2,800	180	390	1,100	1.1	--	--	--
	10/30/2002	156.91	10.17	146.74	0.00	--	--	--	12,000	2,700	45	150	87	<10	--	--	--
	1/8/2003	156.91	3.43	153.48	0.00	--	--	--	3,900	570	47	120	240	<2.5	--	--	--
	4/9/2003	156.91	4.30	152.61	0.00	--	--	--	12,000	1,100	95	290	460	<5.0	--	--	--
	7/9/2003	156.91	6.47	150.44	sheen	--	--	--	14,000	1,600	93	290	460	<10	--	--	--
	10/9/2003	156.91	9.59	147.32	0.00	--	--	--	12,000	2,300	49	180	170	<5.0	--	--	--
	1/8/2004	156.91	6.35	150.56	sheen	--	--	--	4,400	570	39	120	210	<3.0	--	--	--
	4/9/2004	156.91	5.06	151.85	0.00	--	--	--	11,000	1,700	97	270	500	<2.5	--	--	--
	6/24/2004	156.91	7.75	149.16	0.00	--	--	--	8,500	1,500	52	160	220	<5.0	--	--	--
	9/16/2004	156.91	11.04	145.87	0.00	--	--	--	8,500	1,700	28	79	68	<5.0	ND	--	--
MW-5	1/13/2005	156.91	2.99	153.92	0.00	--	--	--	2,900	330	17	60	88	1.4	--	--	--
	5/18/2000	158.13	4.01	154.12	0.00	--	--	--	18,000	90	220	700	3,100	<250†	--	--	--
	12/11/2000	158.13	7.86	150.27	0.00	--	--	--	5,200	99	46	200	650	<100†	--	--	--
	3/1/2001	157.42	3.31	154.11	0.00	--	--	--	17,000	20	110	530	2,100	<10	<3.0 to <30	<3.0	<3.0
	5/29/2001	157.42	6.81	150.61	0.00	--	--	--	5,900	70	23	100	330	<0.50	--	--	--
	7/20/2001	157.42	8.67	148.75	0.00	--	--	--	5,500	93	13	90	310	<1.0	--	--	--
	10/17/2001	157.42	10.39	147.03	0.00	--	--	--	5,200	130	4.6	40	69	1.6	--	--	--
	1/11/2002	157.42	4.13	153.29	0.00	--	--	--	8,300	4.8	27	170	580	<2.0	--	--	--
4/26/2002	157.42	4.93	152.49	0.00	--	--	--	--	6,500	16	29	160	530	<2.0	--	--	--
	7/30/2002	157.42	8.13	149.29	0.00	--	--	--	4,300	38	10	120	250	<1.0	--	--	--

Table 2
GROUNDWATER ELEVATIONS AND ANALYTICAL DATA
421 Santa Rosa Avenue
Santa Rosa, California
Clearwater Group Project No. AB021C

Well-No.	Date	TOC (feet)	DTW (feet)	GWE (feet)	LNAPL (feet)	O&G (µg/L)	TPHmo (µg/L)	TPHD (µg/L)	TPHg (µg/L)	Benzene (µg/L)	T (µg/L)	E (µg/L)	X (µg/L)	MTBE (µg/L)	ETBE, TBA, DIPE, TAME (µg/L)	1,2 DCA (µg/L)	EDB (µg/L)
MW-5	10/30/2002	157.42	10.04	147.38	0.00	--	--	--	3,800	130	8.4	60	80	0.81	--	--	--
	1/8/2003	157.42	3.36	154.06	0.00	--	--	--	6,000	9.8	24.0	130	410	<5.0	--	--	--
	4/9/2003	157.42	4.35	153.07	0.00	--	--	--	12,000	<5.0	24	310	1,000	<5.0	--	--	--
	7/9/2003	157.42	6.43	150.99	0.00	--	--	--	3,200	31	5.9	35	50	<0.50	--	--	--
	10/9/2003	157.42	9.60	147.82	0.00	--	--	--	3,100	40	4.6	22	36	0.90	--	--	--
	1/8/2004	157.42	6.20	151.22	0.00	--	--	--	4,600	4	12.0	100	270	0.51	--	--	--
	4/9/2004	157.42	4.98	152.44	0.00	--	--	--	3,700	8.2	5.3	22	34	0.53	--	--	--
	6/24/2004	157.42	7.85	149.57	0.00	--	--	--	3,900	14.0	4.2	44	85	0.86	--	--	--
	9/16/2004	157.42	11.01	146.41	0.00	--	--	--	2,300	19.0	2.4	8	12	0.97	ND	--	--
	1/13/2005	157.42	3.16	154.26	0.00	--	--	--	2,400	0.5	2.8	32	68	<0.50	--	--	--
MW-6	5/18/2000	159.65	6.00	153.65	0.00	--	--	--	330	4.2	<0.50	12	3.2	<5.0†	--	--	--
	12/11/2000	159.65	10.14	149.51	0.00	--	--	--	130*	0.96	<0.50	<0.50	<0.50	<5.0†	--	--	--
	3/1/2001	158.95	5.77	153.18	0.00	--	--	--	200	<0.50	<0.50	5.3	<0.50	<0.50	<0.50 to <5.0	<0.50	<0.50
	5/29/2001	158.95	8.46	150.49	0.00	--	--	--	120	<0.50	<0.50	1.1	<0.50	<0.50	--	--	--
	7/20/2001	158.95	10.27	148.68	0.00	--	--	--	<50	<0.50	<0.50	<0.50	<0.50	<0.50	--	--	--
	10/17/2001	158.95	11.78	147.17	0.00	--	--	--	<50	<0.50	<0.50	0.72	<0.50	<0.50	--	--	--
	1/11/2002	158.95	5.48	153.47	0.00	--	--	--	410	<0.50	<0.50	6.5	<0.50	<0.50	--	--	--
	4/26/2002	158.95	9.74	149.21	0.00	--	--	--	<50	<0.50	<0.50	<0.50	<0.50	<0.50	--	--	--
	7/30/2002	158.95	9.60	149.35	0.00	--	--	--	<50	<0.50	<0.50	<0.50	<0.50	<0.50	--	--	--
	10/30/2002	158.95	11.55	147.40	0.00	--	--	--	260	<0.50	<0.50	5.8	<0.50	<0.50	--	--	--
MW-7	1/8/2003	158.95	4.97	153.98	0.00	--	--	--	87	<0.50	<0.50	1.1	<0.50	<0.50	--	--	--
	4/9/2003	158.95	6.05	152.90	0.00	--	--	--	<50	<0.50	<0.50	<0.50	<0.50	<0.50	--	--	--
	7/9/2003	158.95	8.02	150.93	0.00	--	--	--	360	17	<0.50	5.4	<0.50	0.55	--	--	--
	10/9/2003	158.95	10.89	148.06	0.00	--	--	--	<50	<0.50	<0.50	<0.50	<0.50	<0.50	--	--	--
	1/8/2004	158.95	4.50	154.45	0.00	--	--	--	140	<0.50	<0.50	0.82	<0.50	<0.50	--	--	--
	4/9/2004	158.95	6.42	152.53	0.00	--	--	--	53	<0.50	<0.50	1.00	<0.50	<0.50	--	--	--
	6/24/2004	158.95	9.33	149.62	0.00	--	--	--	<50	<0.50	<0.50	<0.50	<0.50	<0.50	--	--	--
	9/16/2004	158.95	12.28	146.67	0.00	--	--	--	<50	<0.50	0.67	0.68	1.30	<0.50	ND	--	--
	1/13/2005	158.95	4.32	154.63	0.00	--	--	--	180	<0.50	<0.50	2.90	<0.50	<0.50	--	--	--
	5/18/2000	160.28	8.82	151.46	0.00	--	--	--	430	150	1.5	17	21	<5.0†	--	--	--
MW-7	12/11/2000	160.28	13.32	146.96	0.00	--	--	--	<50	<0.5	<0.5	<0.5	<0.5	<5.0†	--	--	--
	3/1/2001	159.58	7.57	152.01	0.00	--	--	--	840	430	<1.0	<1.0	<1.0	6.8	TBA = 20	<1.0	<1.0
	5/29/2001	159.58	11.11	148.47	0.00	--	--	--	<50	<0.50	<0.50	<0.50	<0.50	1.7	--	--	--
	7/20/2001	159.58	12.72	146.86	0.00	--	--	--	<50	<0.50	<0.50	<0.50	<0.50	1.6	--	--	--
	10/17/2001	159.58	14.38	145.20	0.00	--	--	--	<50	<0.50	<0.50	<0.50	<0.50	1.9	--	--	--
	1/11/2002	159.58	7.50	152.08	0.00	--	--	--	140	57	<0.50	<0.50	<0.50	5.9	--	--	--
	4/26/2002	159.58	9.67	149.91	0.00	--	--	--	140	16	<0.50	3.2	<0.50	2.3	--	--	--
	7/30/2002	159.58	12.24	147.34	0.00	--	--	--	<50	<0.50	<0.50	<0.50	<0.50	1.7	--	--	--
	10/30/2002	159.58	14.17	145.41	0.00	--	--	--	<50	<0.50	<0.50	<0.50	<0.50	1.6	--	--	--
	1/8/2003	159.58	7.26	152.32	0.00	--	--	--	61	18	<0.50	<0.50	<0.50	4.3	--	--	--
MW-7	4/9/2003	159.58	8.85	150.73	0.00	--	--	--	510	110	<0.50	3.8	5.5	4.3	--	--	--
	7/9/2003	159.58	10.77	148.81	0.00	--	--	--	170	<0.50	<0.50	<0.50	<0.50	3.3	--	--	--
	10/9/2003	159.58	13.50	146.08	0.00	--	--	--	<50	<0.50	<0.50	<0.50	<0.50	2.0	--	--	--
	1/8/2004	159.58	7.36	152.22	0.00	--	--	--	190	62	<0.50	<0.50	<0.50	7.0	--	--	--
	4/9/2004	159.58	Not Monitored due to vehicle obstructing well access.			--	--	--	<0.50	<0.50	<0.50	<0.50	<0.50	2.30	--	--	--
	6/24/2004	159.58	11.91	147.67	0.00	--	--	--	53	<0.50	0.59	0.66	2.20	2.80	ND	--	--
9/16/2004	159.58	14.97	144.61	0.00		--	--	--									

Table 2
GROUNDWATER ELEVATIONS AND ANALYTICAL DATA

421 Santa Rosa Avenue
Santa Rosa, California
Clearwater Group Project No. AB021C

Well No.	Date	TOC (feet)	DTW (feet)	GWE (feet)	LNAPL (feet)	O&G (µg/L)	TPHmo (µg/L)	TPHd (µg/L)	TPHg (µg/L)	Benzene (µg/L)	T (µg/L)	E (µg/L)	X (µg/L)	MTBE (µg/L)	ETBE, TBA, DIPE, TAME (µg/L)	1,2 DCA (µg/L)	EDB (µg/L)
MW-7	1/13/2005	159.58	6.68	152.90	0.00	--	--	--	490	180	16.00	2.10	11.00	3.90	--	--	--
MW-8	12/11/2000	159.98	13.11	146.87	0.00	--	--	--	<50	<0.50	<0.50	<0.50	<0.50	<5.0†	--	--	--
	3/1/2001	159.29	7.06	152.23	0.00	--	--	--	<50	<0.50	<0.50	<0.50	<0.50	2.1	<0.50 to <5.0	<0.50	<0.50
	5/29/2001	159.29	10.88	148.41	0.00	--	--	--	<50	<0.50	<0.50	<0.50	<0.50	1.6	--	--	--
	7/20/2001	159.29	12.43	146.86	0.00	--	--	--	<50	<0.50	<0.50	<0.50	<0.50	1.7	--	--	--
	10/17/2001	159.29	13.47	145.82	0.00	--	--	--	<50	<0.50	<0.50	<0.50	<0.50	2.1	--	--	--
	1/11/2002	159.29	7.04	152.25	0.00	--	--	--	<50	<0.50	<0.50	<0.50	<0.50	1.9	--	--	--
	4/26/2002	159.29	8.59	150.70	0.00	--	--	--	<50	<0.50	<0.50	<0.50	<0.50	2.9	--	--	--
	7/30/2002	159.29	11.95	147.34	0.00	--	--	--	<50	<0.50	<0.50	<0.50	<0.50	3.2	--	--	--
	10/30/2002	159.29	13.91	145.38	0.00	--	--	--	<50	<0.50	<0.50	<0.50	<0.50	2.7	--	--	--
	1/8/2003	159.29	7.14	152.15	0.00	--	--	--	<50	<0.50	<0.50	<0.50	<0.50	3.5	--	--	--
	4/9/2003	159.29	8.67	150.62	0.00	--	--	--	<50	<0.50	<0.50	<0.50	<0.50	5.1	--	--	--
	7/9/2003	159.29	10.54	148.75	0.00	--	--	--	<50	<0.50	<0.50	<0.50	<0.50	4.1	--	--	--
	10/9/2003	159.29	13.25	146.04	0.00	--	--	--	<50	<0.50	<0.50	<0.50	<0.50	3.1	--	--	--
	1/8/2004	159.29	7.80	151.49	0.00	--	--	--	<50	<0.50	<0.50	<0.50	<0.50	6.0	--	--	--
	4/9/2004	159.29	9.03	150.26	0.00	--	--	--	<50	<0.50	<0.50	<0.50	<0.50	5.7	--	--	--
	6/24/2004	159.29	11.72	147.57	0.00	--	--	--	<50	<0.50	<0.50	<0.50	<0.50	4.6	--	--	--
	9/16/2004	159.29	14.69	144.60	0.00	--	--	--	52	2.0	2.4	2.0	6.5	5.1	--	--	--
	1/13/2005	159.29	6.59	152.70	0.00	--	--	--	<50	<0.50	<0.50	<0.50	<0.50	2.2	--	--	--
MW-9	12/11/2000	159.39	12.61	146.78	0.00	--	--	--	<50	<0.50	<0.50	<0.50	<0.50	<5.0†	--	--	--
	3/1/2001	158.69	6.94	151.75	0.00	--	--	--	<50	<0.50	<0.50	<0.50	<0.50	2.0	TBA = 5.1	<0.50	<0.50
	5/29/2001	158.69	10.40	148.29	0.00	--	--	--	<50	<0.50	<0.50	<0.50	<0.50	3.5	--	--	--
	7/20/2001	158.69	11.98	146.71	0.00	--	--	--	<50	<0.50	<0.50	<0.50	<0.50	1.6	--	--	--
	10/17/2001	158.69	13.61	145.08	0.00	--	--	--	<50	<0.50	<0.50	<0.50	<0.50	4.9	--	--	--
	1/11/2002	158.69	7.02	151.67	0.00	--	--	--	<50	<0.50	<0.50	<0.50	<0.50	41	--	--	--
	4/26/2002	158.69	9.04	149.65	0.00	--	--	--	<50	<0.50	<0.50	<0.50	<0.50	18	--	--	--
	7/30/2002	158.69	11.48	147.21	0.00	--	--	--	<50	<0.50	<0.50	<0.50	<0.50	9.9	--	--	--
	10/30/2002	158.69	13.38	145.31	0.00	--	--	--	<50	<0.50	<0.50	<0.50	<0.50	12	--	--	--
	1/8/2003	158.69	6.94	151.75	0.00	--	--	--	<50	<0.50	<0.50	<0.50	<0.50	44	--	--	--
	4/9/2003	158.69	8.25	150.44	0.00	--	--	--	<50	<0.50	<0.50	<0.50	<0.50	15	--	--	--
	7/9/2003	158.69	10.09	148.60	0.00	--	--	--	<50	<0.50	<0.50	<0.50	<0.50	18	--	--	--
	10/9/2003	158.69	12.74	145.95	0.00	--	--	--	<50	<0.50	<0.50	<0.50	<0.50	12	--	--	--
	1/8/2004	158.69	6.70	151.99	0.00	--	--	--	<50	<0.50	<0.50	<0.50	<0.50	26	--	--	--
	4/9/2004	158.69	8.55	150.14	0.00	--	--	--	<50	<0.50	<0.50	<0.50	<0.50	7	--	--	--
	6/24/2004	158.69	11.18	147.51	0.00	--	--	--	<50	<0.50	<0.50	<0.50	<0.50	12	--	--	--
	9/16/2004	158.69	14.17	144.52	0.00	--	--	--	150	4.3	6.9	6.9	23	8.6	ND	--	--
	1/13/2005	158.69	6.16	152.53	0.00	--	--	--	<50	<0.50	<0.50	<0.50	<0.50	20.0	--	--	--
SB-14-H20 SB-15-H20 SB-16-H20 SB-18-H20 SB-19-H20 SB-24-H20 SB-26-H20	9/9/1994	--	--	--	--	--	--	--	1,800	580	71	120	350	--	--	--	--
	9/9/1994	--	--	--	--	--	--	--	950	240	160	48	220	--	--	--	--
	9/9/1994	--	--	--	--	--	--	--	1,400	250	34	120	420	--	--	--	--
	9/9/1994	--	--	--	--	--	--	--	18	<0.50	<0.50	<0.50	2.4	--	--	--	--
	9/8/1994	--	--	--	--	<5,000	<1,000	<1,000	36	<0.50	2.7	1.8	7.7	--	--	<0.50	--
	9/8/1994	--	--	--	--	<5,000	<1,000	<1,000	22	<0.50	0.5	<0.50	1.8	--	--	2.0	--
	9/8/1994	--	--	--	--	<5,000	<1,000	9,800^	12,000	2,000	1,600	380	2,100	--	--	0.7	--

Table 2
GROUNDWATER ELEVATIONS AND ANALYTICAL DATA
 421 Santa Rosa Avenue
 Santa Rosa, California
 Clearwater Group Project No. AB021C

Well-No.	Date	TOC (feet)	DTW (feet)	GWE (feet)	LNAPL (feet)	O&G (µg/L)	TPHmo (µg/L)	TPHd (µg/L)	TPHg (µg/L)	Benzene (µg/L)	T (µg/L)	E (µg/L)	X (µg/L)	MTBE (µg/L)	DIPE, TAME (µg/L)	ETBE, TBA, 1,2 DCA (µg/L)	EDB (µg/L)
Notes: Well designation Sample collection date Elevation at the top of the well casing referenced to City of Santa Rosa bench mark C-41, relative to MSL as of 3/1/01 Depth to water Ground water elevation Light Non-Aqueous Phase Liquid hydrocarbons present, sheen = <0.01-foot thick Oil Grease using DHOS Method 553 Total Petroleum Hydrocarbons as Motor Oil by EPA Method 8015M Total Petroleum Hydrocarbons as Diesel by EPA Method 8015M Total Petroleum Hydrocarbons as Gasoline by EPA Method 8015M or 8260B Benzene, Toluene, Ethylbenzene, and total Xylenes by EPA Method 8020 or 8260B Methyl tert-Butyl Ether by EPA Method 8260B Fuel Oxygenates by EPA Method 8260B 1,2-Dichloroethane by EPA Method 8260B 1,2-Dibromoethane by EPA Method 8260B micrograms per liter (approximately equal to parts per billion) Not tested, not measured Not detected in concentrations exceeding the indicated laboratory reporting limit Laboratory reports lighter than diesel range hydrocarbons present in sample (from GPI reports) Laboratory report indicates chromatogram atypical of gasoline MTBE by EPA Method 8020																	
Notes:																	
Well No.																	
Date																	
TOC																	
DTW																	
GWE																	
LNAPL																	
O&G																	
TPHmo																	
TPHd																	
TPHg																	
BTEX																	
Notes:																	
MTBE																	
ETBE, TBA, DIPE, TAME																	
1,2 DCA																	
EDB																	
µg/L																	
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†																	

Table 3
GROUNDWATER ELEVATIONS AND ANALYTICAL DATA
421 Santa Rosa Avenue
Santa Rosa, California
Clearwater Group Project No. AB021C

Well No.	Date	TPHg (µg/L)	D.O. (mg/L)	Ammonia (mg/L)	orth- Phosphate (mg/L)	Nitrate (mg/L)	Sulfate (mg/L)	pH	Aerobic		Anaerobic	
									Total Heterotrophs (cfu/mL)	Hydrocarbon Degraders (cfu/mL)	Total Heterotrophs (cfu/mL)	Hydrocarbon Degraders (cfu/mL)
MW-1A	6/24/2004	44,000	4.5	2.2	1.1	1.1	42	6.60	30,000	600	3x10 ⁴	600
MW-7	6/24/2004	<50	4.4	11.6	0.8	4.4	266	6.32	800,000	<10	8x10 ⁵	<10
MW-9	6/24/2004	<50	4.3	1.4	1.0	3.6	52	6.38	400,000	60	4x10 ⁵	60

Notes:

Well No. : Well designation
Date : Sample collection date
Microbial Counts: Performed by proprietary methods at Cyro Culture Environmental Biotechnology
cfu/mL: Colony forming units per milliliter
D.O.: Dissolved oxygen
--- : Constituent not analyzed
Eh: Reduction-oxidation potential
##.##: Parameters measured in Laboratory
µg/L: micrograms per liter
mg/L: milligrams per liter
mV: millivolts
J: The result is flagged with a "J" to indicate that it is an estimate

APPENDIX B

Chemical Oxidation Information

Chemical Oxidation

By

James A. Jacobs

In-situ chemical oxidizers rapidly treat soils contaminated with toxic and recalcitrant organic wastes (Jacobs, 1995, 1996, 1997). In-situ oxidation uses contact chemistry of the oxidizing agent to react with petroleum hydrocarbons, volatile organic compounds, munitions, certain pesticides and wood preservatives. The gasoline additive, methyl tertiary butyl ether (MTBE) has been shown to break down with Fenton's chemistry (Jacobs et al. , 2000, Leethem, 2002, Kelly et al., 2002). The two most common liquid oxidizers used in soil and groundwater remediation are hydrogen peroxide and potassium permanganate. These oxidizers are non-selective and will oxidize the contaminants, as well as natural organic material (tree roots, organic carbon), reduced metals, carbonates, and sulfides. Liquid oxidants can act as solvents, desorbing contaminants from soil particles. Several sites have been observed where the concentrations in groundwater increase after the first treatment event, while the vadose zone decreases in contaminant concentrations. This rebound effect is noted, however after several treatment events total contaminant concentrations are reduced in both groundwater and vadose zones.

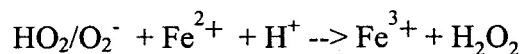
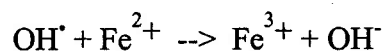
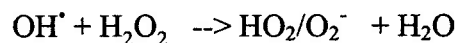
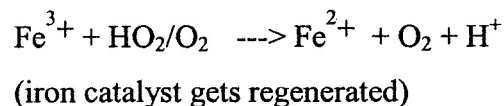
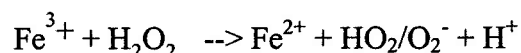
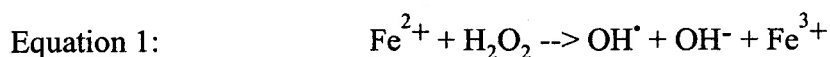
Tables 1 and 2 show how hydrogen peroxide and potassium permanganate relate to other commonly used oxidizers. A summary of the advantages and limitations of these three oxidizers is presented in Table 3. Other oxidants are available, but are less commonly used due to cost, safety and handling issues or potential toxic by-products.

Hydrogen Peroxide

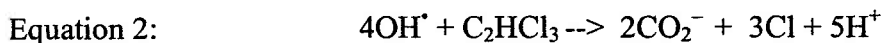
A common oxidizer used for in-situ applications is hydrogen peroxide (H_2O_2). Hydrogen peroxide is the most common peroxide in commerce. Pure hydrogen peroxide and its aqueous solutions are clear liquids resembling water. Unlike water, the hydrogen peroxide has a slightly sharp and distinctive odor. Low concentrations of hydrogen peroxide are sold in drug stores (1-3%) as a mild antiseptic.

Chemistry where iron and hydrogen peroxide react to form hydroxyl radicals and other by-products as shown in Equation 1.

The double bonds, C=C, that characterize chlorinated ethenes are more reactive than the single C-C bonds of chlorinated ethanes. Therefore, PCE and TCE are more susceptible to chemical oxidation than TCA. Although all these chemicals are susceptible to chemical oxidation, relative resistance to oxidation from highest to lowest: PCE, TCE, vinyl chloride, phenanthrene, benzene and hexane. The oxidation reaction for a common solvent, trichloroethene (TCE), forms several unstable daughter products (epoxides), then breaks down to ketones and aldehydes, finally yielding carbon dioxide, water and chloride ions (Suthersan, 2002). The oxidation of TCE is shown in Equation 2:



OH^\bullet = hydroxyl radical



Hydrogen peroxide is one of the earliest chemical oxidants to be discovered and used in industry. It was discovered in the late 1700s and was commercialized in the early 1800s. Hydrogen peroxide works as a remedial treatment chemical in two ways: free radical production and direct chemical oxidation using hydrogen peroxide.

A British Professor H.J.H. Fenton (1893, 1894) described the exothermic and somewhat violent reaction of hydrogen peroxide with iron salts (ferrous sulfate). Fenton's chemistry or Fenton's reagent uses a transition metal catalyst or an acid to enhance the oxidation chemical reaction of hydrogen peroxide by producing the hydroxyl radical.

For in-situ chemical oxidation, the metal catalyst is usually provided by iron oxides within the soil or fill material, or added separately as a solubilized iron salt, such as iron sulfate. In addition, pH adjustment using an acid such as sulfuric (H_2SO_4), is common since the chemical oxidation is more rapid and efficient under lower pH conditions (pH 2-4 is optimal). Fenton's chemistry has been well documented for over 100 years and has been in use in water treatment plants for over 50 years. The supportive chemical processes which essentially results in the destruction of petroleum hydrocarbons, and other volatile organic compounds, are well-documented (Watts, 1991, 1992 and 1994). Although Fenton's chemistry has been documented for well over 100 years, it has been employee safety and handling issues that have kept large numbers of environmental contractors from using in-situ chemical oxidation technology. Although this technology can be used safely, significant safety planning, worker training, personal protective equipment, on-site supervision and monitoring must be an integral part of all oxidation projects.

When chemical oxidant H_2O_2 is injected at concentrations of 10 to 35% into the subsurface, it decomposes readily into reactive hydroxyl radicals (OH^\bullet) and water. The hydroxyl radical (OH^\bullet) in the subsurface can be used to rapidly mineralize hydrocarbon, solvent and other contaminants to water and carbon dioxide. This reaction is enhanced in the presence of iron. Iron is naturally occurring in soil and groundwater or can be added during the injection process, if needed. The reaction is based on the principle of Fenton's

The hydroxyl radical that attacks the carbon-hydrogen bonds is capable of degrading many chlorinated solvents, chloroalkenes, esters, aromatics, pesticides and other recalcitrant compounds such as MTBE, PCP and PCB. The Fenton's chemistry reaction is highly complex. The iron cycles between the Fe(II) and Fe(III) oxidation states yields the hydroxyl radical and other by products (Suthersan, 2002).

Residual H_2O_2 not used in the oxidation process breaks-down to water and oxygen in a matter of hours. In addition to the reaction described in Equation 2, there are also a large number of competing reactions including the free radical scavengers, most importantly, carbonate and bicarbonate alkalinity, that will greatly affect the overall reaction scheme. In addition, H_2O_2 can serve as an oxygen source for microbes in the subsurface to enhance biodegradation of contaminants.

Although handling hydrogen peroxide and other oxidants requires significant safety training and planning, the oxidant is effective at remediation of a variety of organic contaminants and is relatively inexpensive. The reaction time for hydrogen peroxide in the subsurface is usually within minutes to at most, hours. Rise in temperatures in the subsurface illustrates the exothermic nature of the oxidation process. Rapid degradation of hydrocarbons, solvents and organic compounds is the goal of in-situ chemical oxidation, not the violent decomposition of hydrogen peroxide, which does occur at elevated reaction temperatures.

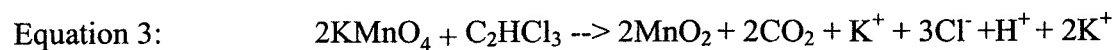
Based on field research, the optimum reaction temperature is relatively low, as measured on the reaction foam in the field using infrared thermal meters is 35°C to 41°C . Increases in temperature beyond about 57°C the peroxide becomes more volatile as it starts to produce a wispy white vapor. The gas is water vapor and carbon dioxide, the end products of chemical oxidation. Subsurface reaction temperatures, as measured using the infrared thermal meter in the range of 82°C to 93°C are explosive and unsafe. Temperatures of subsurface chemical reactions can be monitored and lowered by adding water, lowering concentrations of the catalyst or oxidant and reducing injection pressures.

Hydrogen peroxide reacts in an optimal manner in lower pH settings, with lower alkalinity readings. In some cases, acids are used to lower pH. The end products of oxidation are carbon dioxide and water. Trace chloride from chlorinated compounds will likely combine with sodium or calcium ions to form salts or with hydrogen to form weak acids. Careful evaluation of soil and water chemistry using a bench test with soil and water samples is recommended prior to the start of any injection process. Due to the rapid reaction time, subsurface spacing of injection ports must be relatively close which is dependent on lithology. Clays and silts which are problematic to remediate in-situ, typically require 0.6 to 1 meter spacing, whereas injection ports for clean sand and gravels can be placed at 2 to 3 meter spacing.

Potassium Permanganate

Potassium permanganate has been used in water treatment plants for several decades because it can oxidize phenols, Fe^{2+} , S^{2-} and taste and odor producing compounds (Suthersan, 2002). Although a weaker oxidizer than hydrogen peroxide, potassium permanganate (KMnO_4) lasts longer in the environment (hours to days) and can react in an environment with much higher pH and alkalinity than hydrogen peroxide. For field use, potassium permanganate is shipped as a gray crystalline powder and is mixed with water creating a deep purple liquid. The bright purple color can be used as an indicator for non-reacted potassium permanganate, whereas the reacted permanganate is dark chocolate brown or black in color, indicating the presence of manganese dioxide (MnO_2) precipitate. Manganese dioxide is a natural compound commonly found in soils.

The solubility of KMnO_4 is strongly influenced by temperature and at 30° C, has a concentration of slightly over 8%. The pH range is critical in being able to determine whether the oxidation reaction will be fast or slow. The chemical formula for chemical oxidation of TCE using potassium permanganate is shown below in Equation 3 (Nickelsen, et. al., 1992):



The oxidation end products when using potassium permanganate include carbon dioxide, water, and the potassium ion (K^+).

Delivery of Liquid Chemical Oxidizers

For both liquid oxidizers hydrogen peroxide and potassium permanganate, an integral part of in-situ remediation planning is the evaluation of a safe delivery method of the treatment chemicals. Jetting is an old groundwater development technology that has been modified for remediation purposes. The technology for high pressure, low to high volume injection of nutrients into the subsurface using a 12.5 mm (1/2-inch) diameter hand-held wand or lance driven into the ground has been widely used for several decades. The jetting technology, at its most basic, uses tree root feeder systems to inject nutrients and other chemicals into the subsurface by means of a high pressure injector tip on the end of a small-diameter, 2 to 5 foot long steel wand. A more powerful and versatile jetting system has been developed to efficiently implement a variety of remediation processes including chemical oxidation, bioremediation, pH adjustment and metals stabilization. The 3 to 4.6 meter long lances use high-pressure liquid pumps to increase flow at the tip of the wand to pressures from 2,109 to 3,515 meters-head (3,000 to 5,000 psi). At these pressures, the lances are pushed downward into the subsurface with little physical effort. The high-pressure cuts into the soil and the lances descend at velocities up to one foot per second. High-pressure injection points are placed on close spacing, from 1-meter centers for clays to 3 meter centers for clean gravels. The high pressures allow for the treatment liquids to be dispersed into the soil matrix both vertically and laterally, as well as into the groundwater. Field experience shows that clays start to fracture at about 844 meters-head (1,200 psi) tip pressure. At these pressures, the pressure gauges build up and sustain the pressure, and the fracture occurs at breakthrough and the pressure immediately drops significantly until another zone is fractured. The fractures in clays and other low permeability sediments create preferred remedial pathways that may extend 3 meters or more, however, the matrix of the fractured low permeability soil is unlikely to be uniformly treated.

After the reaction occurs, additional treatment events may be required to reduce contaminants to regulatory approved levels. RIP® projects performed for consultants indicated a radius of influence around injection ports up to 8.6 meters. After the liquids are injected and the jetting tool is removed from the subsurface, no pieces or parts are left

behind. The injection holes are then either abandoned as is or sealed with cement grout or bentonite, as needed.

The jetting injector wands can be used to remediate limited access areas such as underneath slabs, railways, and buildings, around tanks, pipelines and subsurface utilities; and into hillsides, excavation pits and stockpiles. Jetting technology has the capability to remediate a variety of constituents both in-situ or ex-situ including petroleum hydrocarbons, BTEX, MTBE, chlorinated solvents, soluble inorganics, phenols, PCBs, PAHs, and other organic and inorganic contaminants. The flexibility and accuracy of this injection delivery system provides distinct advantages over both conventional in-situ and ex-situ remediation systems. As a result, the jetting technology can provide appreciable savings in cost and time over traditional remediation technologies. Probe injector rods have been used successfully with direct push technology (DPT) rigs for greater target depths (4.6 meters to 18 meters).

Another liquid delivery method uses modified direct push (Geoprobe) rods connected to a high-pressure injection pump. This method works at 200 to 600 psi pressure.

Ozone

Ozone (O_3) is a powerful gas phase oxidizer that can be used to treat VOCs, including petroleum hydrocarbons. It must be generated on-site and the gas cannot be stored; therefore all the ozone gas that is generated must be injected into the subsurface or destroyed using an ozone destruction unit on the ozone generator. The ozone gas can be bubbled into closely spaced wells or injection ports that release the bubbles into the aquifer for remediation. The smaller the bubbles, the more surface area and the faster they can travel through small pore spaces. Pushing the ozone gas through a diffusion pipes can produce micro-bubbles. Ozone has a half-life of about 20 minutes. Increased heat, pressure and velocity reduces the ozone concentration output (Harrison, 2000). Adding an oxygen concentrator to the ozone generator on the in-flow end can greatly increase the ozone concentration produced. A hydrogen peroxide drip can be very

effective for catalyzing the ozone to create more hydroxyl radicals, the main treatment molecule.

SAFETY: For all types of in-situ chemical oxidation methods, chemical compatibility of the injection equipment, personal protective equipment and safety procedures become critical with the injection of potentially dangerous chemicals including oxidizers, acids, bases, and other chemicals. Chemical compatibility of the injection equipment components and safety procedures for employees and contractors become critical with the injection of strong acids, bases, oxidants and other chemicals.

BIOREMEDIATION: Chemical oxidants can also serve as an oxygen source for microbes in the subsurface to enhance biodegradation of contaminants. Therefore, many in-situ chemical oxidation projects are designed to move into a second, longer-term bioremediation phase due to all the newly available oxygen in the subsurface. Potassium and sodium permanganate do not kill microbes. Hydrogen peroxide and ozone at higher concentrations will kill microbes, however, the oxygen rich treatment area will be attractive to indigenous populations in adjacent zones which will move into treated areas within a short period of time.

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TABLE 1
COMPARATIVE RELATIVE STRENGTH OF VARIOUS OXIDANTS

Species	Chemical Formula	Standard REDOX Potential Eo (Volts)	Oxidants commonly used in chemical oxidation remediation
Fluorine	F ₂	3.0	No
Hydroxyl Radical (Created with Fenton's Chemistry)	HO°	2.8	Yes – with acid or iron catalyst
Oxygen Radical	[•] O ₂ ⁻ (Superoxide)	2.4	No
Ozone	O ₃	2.1	Yes - sparged
Hydrogen Peroxide	H ₂ O ₂	1.8	Yes – see *OH
Potassium Permanganate	KMnO ₄ ⁻	1.7	Yes – mixed with water and injected
Hydrochlorous Acid	HOCl	1.5	No
Chlorine Dioxide	ClO ₂	1.5	No
Chlorine	Cl ₂	1.4	No
Oxygen	O ₂	1.2	No
Bromine	Br ₂	1.1	No
Iodine	I ₂	0.8	No
ACTIVATED OXYGEN SPECIES (Suthersan, 2002)	Formed by action of light on natural organic matter, peroxides or various inorganic catalysts		
Singlet Oxygen	¹ O ₂		
Protonated Superoxide	HO ₂ °		
Hydrogen Peroxide	H ₂ O ₂		
Hydroperoxide anion	H ₂ O ₂ /HO ₂ ⁻		
Hydroxyl Radical	HO°		
Ozone	O ₃		

TABLE 2
CHEMICAL OXIDATION: OXIDIZING AGENTS

Commonly used for chemical oxidation	Less Common:
Hydrogen Peroxide (Hydroxyl Radical) (liquid)	Sodium permanganate (solid)
Potassium Permanganate (solid)	Peracetic acid (liquid)
Ozone (gas)	Calcium peroxide (solid)
	Sodium peroxide (solid)
Note: solids soluble in water	Sodium perborate (solid)
	Sodium percarbonate (solid)
	Sodium persulfate (solid)
	Magnesium peroxide (solid)

TABLE 3
SUMMARY OF ADVANTAGES AND LIMITATIONS
OF TWO COMMON OXIDIZERS

	HYDROGEN PEROXIDE (H ₂ O ₂) (with acid or iron catalyst as Fenton's Chemistry)	POTASSIUM PERMANGANATE (KMnO ₄)
FACTOR	DESCRIPTION	DESCRIPTION
Reactivity	Very fast, strong reaction	Fast, strong reaction
Reactant half-life	Seconds – minutes	Minutes – hours
Availability	Widely Available	Generally available
Phase	Clear liquid	Gray powder, mixed with water to about 5-6% turns to bright purple color. Over 8% concentration begins to precipitate.
Target Chemicals (Leethem et al., 2002)	Works well with: Chlorinated alkenes, PAHs, MTBE, BTEX, Olefins (Alkenes);	Works well with: Chlorinated alkenes, phenols, sulfide/organosulfur compounds, olefins (Alkenes)
Does not work well on: (Leethem et al., 2002)	Does not work well on Chlorinated alkanes, some alkanes	Does not work well on: gasoline, diesel, MTBE, BTEX, alkanes, methylene chloride, carbon tetrachloride
Safety and Handling	Special handling and safety precautions: PPE for skin, eyes, mucous membranes, lungs. Serious white burns if handled poorly.	Special handling and safety precautions: PPE for skin, eyes, mucous membranes, lungs. Purple staining and burns if handled poorly.

pH requirements	Low pH (2-4) optimal; requires acidic environments with low alkalinity (<200 ppm)	Reactive under neutral pH (7); more flexibility with pH and alkalinity than hydrogen peroxide, pH control and catalysts not needed.
Cost	inexpensive	
Reaction by-products	Non-toxic by-products (CO ₂ , H ₂ O)	Non-toxic by-products (CO ₂ , H ₂ O)
Type of oxidizer	Non-selective oxidizer	Non-selective oxidizer
Residuals:	CO ₂ , water, iron salts, O ₂ , chlorides, if chlorinated compounds present.	Mn, K, MnO ₂ , MnO ₄ ⁻ MnO ₂ is an insoluble precipitate that also forms in soil naturally.
Injection Spacing	Close injection port spacing reflects short reaction period (minutes to hours).	Injection spacing can be further apart due to longer reaction time than hydrogen peroxide.
Phase II: Aerobic bioremediation	Kills microbes, reestablished within weeks.	Less toxic to microbes than hydrogen peroxide.
Regulatory Resistance	Low regulatory resistance, as components are H and O.	Higher regulatory resistance due to Mn.
Comments on oxidizing Cr(III) to Cr(VI)	H ₂ O ₂ : The amount of Cr(VI) mobilized depends on the amount present. Cr(VI) will reattenuate within a short time and distance (Suthersan, 2002).	KMnO ₄ : The amount of Cr(VI) mobilized depends on the amount present. Cr(VI) will reattenuate within a short time and distance (Suthersan, 2002).



APPENDIX C

Monitored Natural Attenuation and Monitoring Guidelines

Clearwater Field Protocols and Direct-Push Sampling Procedures

Well Installation and Development Protocols

Well Construction Design for Proposed New Wells

each contaminant. Conservative decay half-life default values from Connor et al (1995) are provided in Table 1. Alternatively, for most realistic results, biodegradation may be modeled based on actual concentrations of electron acceptors, by determining the biodegradation capacity (BC) for each electron acceptor and contaminant concentration (Connor et al, 1995).

The biodegradation capacity is a measure of the actual potential of an electron acceptor (n) to remove contaminant mass. The BC_n is calculated for each contaminant and electron acceptor by dividing the concentration of the acceptor in the groundwater by its utilization factor (UF_n). The UF_n can be easily derived from the stoichiometric equation for the particular degradation reaction and represents the ratio of mass of electron acceptor utilized to the mass of hydrocarbon degraded (Wiedemeier, 1995). Values of UF_n for benzene for each pathway are presented in Table 2. The sum of the BC_n values obtained for the principal electron acceptors is the total biodegradation capacity of the groundwater (BC_T) (Connor et al, 1995). This datum is necessary in contaminant fate and transport models to realistically evaluate the potential for plume attenuation resulting from intrinsic biodegradation.

MTBE is almost completely recalcitrant to biological degradation and does not sorb onto the soil. Due to these properties, MTBE concentrations generally mimic non-attenuated plume transport. Therefore, MTBE may be used as a conservative tracer or "internal standard" for modeling plume transport with no attenuation.

Confirming Natural Attenuation

To best confirm natural attenuation in anticipation of site closure, the assessment and monitoring activities should confirm the following plume characteristics:

- 1) Fieldscale contaminant mass has been reduced (based on historical groundwater analyses). Figure 1 illustrates a generally accepted methodology for calculating residual dissolved contaminant mass.
- 2) Microbial activity is occurring in the plume (based on microbial counts)
- 3) The less recalcitrant compounds are reduced in concentration and extent relative to the more recalcitrant compounds. The approximate order of increasing recalcitrance for BTEX aromatics is: toluene, o-xylene, m- and p-xylene, benzene, ethylbenzene. That is, toluene concentrations should be most attenuated; ethylbenzene least attenuated.
- 3) Electron acceptors such as DO, nitrate and sulfate are depleted within the plume
- 4) Metabolic end-products such as carbon dioxide, hydrogen sulfide and methane have accumulated within the plume relative to outside of the plume.

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(Barker et al, 1995). Pyrite may be precipitated in the soil. Sulfate concentrations in groundwater are naturally higher than those for nitrate. Sulfate concentrations of 100 mg/L might be considered moderate and several hundred mg/L is not uncommon. Concentrations below 40 mg/L are indicative of methanogenic conditions (Cookson, 1995). Sulfate reduction typically occurs when Eh is approximately -200 mV.

Methanogenesis. Under methanogenic conditions (Eh of approximately -250 mV), carbon dioxide and methane are both produced by hydrocarbon oxidation. The utility of measurement of these compounds is discussed below (metabolic end-products).

Carbonate/Hardness/Total alkalinity

One of these associated analyses is typically conducted at the laboratory on collected water samples. Increased carbonate concentration will commonly occur where acidity dissolves carbonates from the soil. Sufficient concentrations of carbonate will buffer the pH and prevent acid toxicity that may result from hydrocarbon degradation. Total alkalinity (as carbonate) concentrations exceeding 100 mg/L may be considered conducive to effective buffering. Dissolved carbon dioxide may be assessed in conjunction with total alkalinity analysis.

Metabolic end-products

Metabolic end-products of hydrocarbon biodegradation include carbon dioxide, water, nitrogen, nitrites, ferrous iron, sulfites, sulfides, hydrogen sulfide, and methane. Carbon dioxide, hydrogen sulfide and methane may be measured with a gas meter at the wellhead. Reduced ferrous iron, sulfite and sulfide may be analyzed in water samples. Sulfides may precipitate into the soil and be under-represented in groundwater samples. Nitrite is metastable and therefore nitrite detection (generally <0.1 mg/L) is indicative of ongoing denitrification. Ammonium ions in excess of 1.0 mg/L may also be indicative of anaerobic conditions. Elevated concentrations of all metabolic end-products should correlate positively with elevated hydrocarbons.

Field measurement of dissolved carbon dioxide (DCD) is of secondary importance but may provide useful data. Dissolved carbon dioxide is derived primarily from the atmosphere. Elevated DCD spatially correlated with decreased DO concentration, may be indicative of aerobic microbial hydrocarbon degradation as DCD is a metabolic end-product. Elevated DCD may also result from anaerobic degradation. High background DCD is a desirable feature in terms of the capacity of the groundwater to buffer decreases in pH produced by microbial hydrocarbon degradation which may otherwise limit biological activity. Carbon dioxide is more soluble than oxygen and average concentrations are around an order of magnitude higher.

Contaminant Fate and Transport Modeling

Plume transport can be modeled using simple analytical equations. Transport assuming no attenuation can be modeled and the results compared with field data to provide a preliminary indication of the extent of natural attenuation. Transport models can be modified to include various natural attenuation factors based on actual site data. Comparison of these modeling results to actual field results can be used to confirm natural attenuation.

To model plume transport, the following basic site characteristics need to be determined:

- Historical dissolved hydrocarbon distribution
- Hydraulic conductivity
- Soil density/porosity
- Aquifer thickness
- Groundwater gradient/depth fluctuations
- Possible preferential migration pathways
- Organic content of the soil, f_{OC} .

Laboratory analysis of soil samples may be necessary to establish f_{OC} , which is useful for modeling sorption. Hydraulic conductivity may be obtained as an estimate from the literature based on soil type (for homogeneous lithologies), or by performing an aquifer test (slug or pump).

For plumes under steady-state conditions, contaminant transport models such as the Domenico Transport Equation can be modified to include the processes of dispersion and sorption to predict contaminant concentrations at a given distance from the source (Connor et al, 1995). In addition, biological and chemical degradation may be collectively modeled by a first-order decay function requiring assignment of a literature-based decay half-life value (in days) for

particularly exposure to atmospheric oxygen; hence the preferred use of a downhole meter. It is necessary to strictly adhere to instructions provided with a given model of instrument. DO meters function by permitting a small quantity of oxygen to diffuse across a porous membrane. Consequently, it is necessary to keep water moving in the vicinity of the membrane to prevent a depletion of DO immediately adjacent to the membrane. This can be achieved manually, by a gentle raising and lowering of the meter in the well. The membrane is delicate and must be carefully maintained.

A negative correlation should occur between DO concentrations and hydrocarbon concentrations. Background concentrations should exceed 1 to 2 mg/L for effective aerobic degradation. DO in groundwater is derived from the atmosphere at the recharge area or the vadose zone. Surface water saturated with oxygen by contact with atmospheric air will contain between approximately 7.5 mg/L at 5°C and 12.75 mg/L at 30°C, though these figures may vary somewhat depending on other chemical parameters. DO concentrations in groundwater are generally less than those for surface water by an amount dependent on the quantity of oxidizable materials (e.g. sulfides) in contact with the groundwater, and the length of time the groundwater has been stored in the aquifer. Background groundwater DO concentrations in shallow aquifers can be as high as 12 mg/L in warm conditions or as low as 1 mg/L in cool conditions. (Hem, 1985). DO may be increased by local groundwater recharge (e.g. irrigation). Aerobic degradation typically occurs when Eh is approximately +800 mV (discussed below).

Anaerobic Electron Acceptors

Analysis of water samples for nitrate, dissolved iron, and/or sulfate can provide data indicative of intrinsic bioremediation. The higher the background concentrations the better, unless they are so high as to create toxicity for the microbes or exceed water quality standards. Depleted dissolved electron acceptor concentrations (except iron, see below) in areas of high hydrocarbon concentration are indicative of microbial degradation.

Nitrate. Nitrate concentrations may be derived by analyzing nitrate plus nitrite as N (EPA Method 353.2). This laboratory method calculates total nitrate, since nitrite is metastable in groundwater and seldom present in sufficient quantities to affect the ionic balance (Wiedemeier et al, 1995). The bulk of nitrates in groundwater are derived from human contamination (e.g., agricultural runoff/septic systems). Background concentrations vary widely with human activity in the site vicinity, and would otherwise be commonly less than 1 mg/L. Concentrations considered indicative of a significant biodegradation capacity might be those in excess of 20 mg/L. Denitrification/nitrate reduction typically occurs when Eh is approximately +750 mV (but more than 0 mV).

Iron. Laboratory analysis of iron concentration may be accomplished by collecting an unfiltered groundwater sample to obtain the total iron content (precipitated and dissolved), or by passing the sample through a 0.45 micron filter immediately after collection to obtain the dissolved iron concentration. Iron in groundwater is derived primarily from soil minerals. Dissolved iron concentrations are very sensitive to changes in pH and Eh. Free dissolved ferric iron can only exist stably under extremely acidic conditions (pH<2) (Hem, 1985). Ferric iron reduction to ferrous iron occurs at intermediate Eh values. Under aerobic, moderately acidic or alkaline conditions, dissolved iron is typically present as a hydroxide; the ferric species is ferric orthohydroxide (Wiedemeier et al, 1995). Dissolved ferric iron is usually rapidly reprecipitated as a sulfide, oxide or hydroxide. Since microbes utilize insoluble sedimentary ferric iron oxides as their energy source, producing more soluble ferrous iron, an increase in total dissolved iron is indicative of microbial hydrocarbon degradation.

The solubility of ferrous iron is significantly reduced by the presence of sulfides, the end-product of sulfate reduction (Barker et al, 1995). Analytical results of dissolved ferrous iron concentration will likely give an underestimate, since it is not based on the actual amount of ferric hydroxide (the electron acceptor) present in the aquifer, but the amount of reduced ferrous iron (the end-product) remaining in solution at the time of sampling.

Typical background concentrations of total dissolved iron in groundwater are below 1.0 mg/L. Results in excess of 1.0 mg/L indicate iron-reducing conditions (Cookson, 1995) which may have resulted from anaerobic hydrocarbon degradation. High dissolved iron concentrations may also indicate the presence of very fine particulates, low pH, or high organic content. High organic content induces stability of soluble iron complexes (Hem, 1985). Measurement of the total iron content of a sample is useful as a background datum against which to compare changes in the dissolved concentration.

Sulfate. Sulfate is derived primarily from soil minerals. The occurrence of sulfate reduction may be inferred from the presence of black acid volatile sulfide deposits on materials in long-term contact with contaminated groundwater

- Methane (field measurement)
- Alkalinity (EPA method 310.1)
- Dissolved carbon dioxide (with alkalinity or method SM406C)

Certain parameters, notably DO and Eh, may be measured in the field using downhole meters. Most of the other parameters require laboratory analysis of a groundwater sample for accurate quantification. Trends in methane concentrations may be identified using an organic vapor meter fitted with an appropriate filter at the wellhead.

The combination of parameters that Clearwater will monitor at a particular site will depend on site-specific conditions and previous site investigation. The minimum set of parameters as defined by Rifai will always be included for at least one clean (background) well and at least one well representative of mid-plume conditions.

The following sections provide a detailed description of monitoring methods and anticipated results for indicator parameters outlined above.

Microbial Populations

Hydrocarbon degrading bacteria are generally ubiquitous; however, the total population of microbes (measured in counts per liter) is dependent on the available energy source (i.e., hydrocarbons). To evaluate natural attenuation, microbial counts should include separate enumerations for hydrocarbon degrading bacteria and for total heterotrophic bacteria, both normally obtained from cultured plate counts. The ratio of hydrocarbon degraders to total heterotrophs is the most useful in assessing natural attenuation. This ratio should be relatively large in samples from contaminated wells, compared to the ratio in samples from clean wells, indicating a proliferation of the indicator species in contaminated areas, independent of overall microbial population variations. Such a distribution of bacteria may require 1 to 2 years to become established once hydrocarbon contamination is present. As further confirmation, it may be useful to establish that sufficient concentrations of microbial nutrients such as nitrogen and phosphorous are present in the subsurface.

Groundwater typically contains total microbial counts of 10^3 to 10^8 counts per liter. Lower counts in contaminated areas may indicate toxic conditions. In sites with organic rich soils, microbial populations may be high but hydrocarbon degradation may be inhibited because the microbes preferentially degrade the naturally occurring carbon compounds found in the soils (Cookson, 1995).

pH

pH is best measured with a meter or by collecting a sample for laboratory analysis. The probe portion of pH meters must be regularly cleaned and periodically soaked in solutions designed to remove oil and protein build up. Lowered pH corresponding spatially to the plume may be indicative of the production of organic acid metabolic end-products of aerobic hydrocarbon degradation. Uncontaminated groundwater is commonly slightly alkaline, but pH varies widely depending on many natural and human influenced factors. pH between 6 and 8 is optimal for BTEX degradation.

Redox Potential (Eh)

Eh is a measure of electron activity within a solution. Each pathway of degradation is generally restricted to a prescribed range of Eh values. Hydrocarbon degradation reduces the Eh of the system in which it occurs, unless the groundwater recharge rate exceeds the utilization rate of the electron acceptor (this is normally not the case since mixing is limited). Once an electron acceptor has been utilized and thereby depleted in the system, Eh conditions determine which next electron acceptor in the sequence will become predominant.

The utility of Eh measurement is as an adjunct to electron acceptor concentration measurements (discussed below). Eh must be measured in situ to avoid atmospheric influence as described in the section on DO sampling. Eh units are millivolts (mV). Decreased Eh should coincide with elevated contaminant concentrations, and depleted DO. Very low Eh (reducing conditions: <0 mV) should coincide with depleted anaerobic electron acceptors. Table 2 presents Eh values typical of each biodegradation pathway.

Dissolved Oxygen (DO)

DO is best measured with a downhole meter measuring in mg/L. Some meters also read DO as a percentage of saturation at a given temperature, however, the volumetric concentration has more utility in fate and transport models. Measurement of DO and Eh are both sensitive to several factors associated with field methodologies,

dispersivity, D_y) is modeled at 0.33 times D_x ; dispersion in the vertical direction (vertical dispersivity, D_z) is modeled at 0.05 times D_x (Connor, et al., 1995).

Sorption

Contaminants partition between the aqueous phase and the soil matrix. Adsorption onto the soil surface significantly retards migration but does not permanently remove BTEX which may desorb later. Carbon is the most effective sorption material in soils, and although clay minerals and amorphous minerals such as iron hydroxides also have some influence, only sorption to carbon in soil is included in most contaminant fate and transport computer models.

Sorption is controlled by the organic carbon content of soil (f_{OC}), the chemical specific organic carbon partition coefficient (K_{OC}), the soil bulk density (ρ_s), and the water content of the soil as measured by the porosity (ϕ_s). K_{OC} is a measure of the affinity of a given chemical to sorb from water onto solid organic material (Table 1). Once the porosity, bulk density, K_{OC} , and f_{OC} have been established, the retardation factor (R) for the site can be calculated as follows:

$$R = (1 + k_s * \rho_s / \phi_s) \quad \text{where: } k_s = f_{OC} * K_{OC}$$

The retardation factor is used in transport models (discussed below) as a measure of the degree to which the rate of plume migration is reduced by sorption processes.

Hydrolysis etc.

Other chemical reactions such as hydrolysis may reduce contaminant mass without microbial mediation. Hydrolysis occurs when an organic molecule reacts with water or a component ion of water. Unlike biodegradation, hydrolysis is not catalyzed by microorganisms. Hydrolysis has not been observed to reduce BTEX concentrations, but is significant for halogenated volatile organics (solvents, etc.).

Monitoring Groundwater For Natural Attenuation

Assessment and monitoring of natural attenuation should be performed to confirm that intrinsic bioremediation and other forms of natural attenuation are occurring in the subsurface and are sufficient to limit plume migration by achieving an equilibrium between hydraulic transport (advection) and removal/degradation/reduction of mobile contaminants. To confirm natural attenuation, it needs to be demonstrated that intrinsic factors are limiting migration, and that they will continue to do so until the plume has degraded to acceptable levels.

Natural attenuation can be evaluated by monitoring specific indicator parameters over a given period of time. As further confirmation, simple fate and transport models can be applied to the site using the site-specific information obtained. Several lines of evidence will generally need to be combined to provide a convincing case of natural attenuation. First, it is necessary to establish that the plume is stable or being reduced in terms of size and concentrations, by review of historical data, possibly including statistical analysis. At least one year of monitoring data utilizing an adequate distribution of wells should be sufficient. For all chemical parameters, background concentrations need to be established by sampling one or more clean wells. In addition to plume concentrations, Rifai et al., (1995), recommends, at a minimum, monitoring the following parameters:

- Microbial enumeration [total heterotrophic bacteria (plate count), and total hydrocarbon using bacteria (ASTM method G-2)].
- Temperature (field measurement)
- pH (field measurement)
- Dissolved Oxygen (field measurement or EPA Method 360.1)

If DO is depleted relative to background concentrations, additional monitoring for anaerobic processes may be considered and should include the following:

- Eh (field measurement)
- Sulfate (EPA method 300 or 375.4)
- Nitrate/nitrite (EPA method 300, 353.1 or 353.2)
- Dissolved iron (EPA method 200.7)
- Total iron (EPA Method 236.1 or 6010)

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Natural Attenuation Processes and Recommended Monitoring Guidelines

The following document details the processes involved in the natural attenuation of petroleum hydrocarbons in soil and groundwater and presents recommendations for monitoring and confirming these processes. By confirming natural attenuation, a conceptual basis is provided for regulatory site closure.

Natural Attenuation Processes

The predominant attenuation process is intrinsic biodegradation (aerobic and anaerobic) mediated by hydrocarbon degrading bacteria. Other factors in natural attenuation include physical and chemical processes such as volatilization, dispersion, sorption and hydrolysis. Unless otherwise referenced, the following information was derived from McAllister and Chiang (1994).

Aerobic degradation.

In aerobic respiration, microbes utilize dissolved oxygen (DO) as an electron acceptor during hydrocarbon oxidation (degradation), producing carbon dioxide, water, and microbial biomass. The electron acceptor is a substance that facilitates the reaction by taking up the electrons released by oxidation; the electron acceptor then becomes reduced during the process of biodegradation.

The aerobic process is the most important form of biodegradation wherever DO concentrations exceed 1 to 2 mg/L. Under hypoxic conditions (0.1 to 2 mg/L DO), aerobic degradation may occur along the edges of the plume while anaerobic degradation predominates in the center of the plume.

Anaerobic degradation.

Microbes may also degrade hydrocarbons via anaerobic processes by utilizing alternate biochemical pathways when DO concentrations are insufficient for aerobic degradation. Anaerobic degradation is much slower than the aerobic process and not all BTEX compounds (benzene, toluene, ethylbenzene, and xylenes) are consistently degraded. Some studies indicate benzene is recalcitrant to anaerobic degradation while others have demonstrated limited degradation (Rifai et al, 1995). Anaerobic degradation generally occurs in the center of the plume where DO has been depleted by aerobic degradation. Research into the efficacy of anaerobic processes is ongoing.

Anaerobic electron acceptors include [in order of sequential use and decreasing redox potential (Eh)]:

- nitrate (NO_3^-),
- oxides of ferric iron (Fe^{3+}),
- sulfate (SO_4^{2-}),
- water.

The associated biochemical processes are: denitrification (or nitrate reduction), iron reduction, sulfate reduction, and methanogenesis. Manganese (Mn^{4+}) may also function as an electron acceptor. Nitrate and sulfate reduction do not degrade alkanes such as methane, propane, and butane.

Volatilization

Dissolved plume mass can be reduced by volatilization of contaminants to the vapor phase in the unsaturated zone. Normally volatilization is a negligible component of natural attenuation, however, it may contribute 5% or more of total mass loss in shallow (<15 feet), warm and/or fluctuating water table conditions in permeable soils (Rifai et al, 1995).

Dispersion

Mechanical/molecular mixing reduces dissolved concentrations substantially by lateral spread. No dissolved contaminant mass is removed from the system by this process. Dispersion (D) is generally modeled based on the length of the plume (x). Conservative practice calls for dispersion in the downgradient direction (longitudinal dispersivity, D_x) to be modeled at 0.1 times the plume length. Dispersion in the transverse direction (transverse

Rifai, H.S. et al, 1995. "Intrinsic Bioattenuation for Subsurface Restoration." In R. E. Hincsee, J. T. Wilson, and D. C. Downey (Eds.), *Intrinsic Bioremediation*, pp. 1 - 25. Battelle Press, Columbus, OH.

Wiedemeier, T.H., 1995. "Patterns of Intrinsic Bioremediation at Two U.S. Air Force Bases." In R. E. Hincsee, J. T. Wilson, and D. C. Downey (Eds.), *Intrinsic Bioremediation*, pp. 31 - 50. Battelle Press, Columbus, OH.

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Direct-Push Drilling Investigation Procedures

The direct push method of soil boring has several advantages over hollow-stem auger drill rigs. The direct push method produces no drill cuttings and is capable of 150 to 200 feet of boring or well installation per work day. Direct push can be used for soil gas surveys, soil sampling, groundwater sampling, installation of small-diameter monitoring wells, and components of remediation systems such as air sparge points. The equipment required to perform direct push work is varied ranging from a roto-hammer and operator to a pickup truck-mounted rig capable of substantial static downward force combined with percussive force. This method allows subsurface investigation work to be performed in areas inaccessible to conventional drill rigs such as in basements, beneath canopies, or below power lines. Direct push equipment is ideal at sites with unconsolidated soil or overburden, and for sampling depths of less than 30 feet. This method is not appropriate for boring through bedrock or gravelly soils.

Permitting and Site Preparation

Prior to direct push boring work, Clearwater Group will obtain all necessary permits and locate all underground and above ground utilities through Underground Service Alert (USA) and a thorough site inspection. All drilling equipment will be inspected daily and will be maintained in safe operating condition. All down-hole drilling equipment will be cleaned prior to arriving on-site. Working components of the rig near the borehole, as well as driven casing and sampling equipment will be thoroughly decontaminated between each boring location by either steam cleaning or washing with an Alconox® solution. All drilling and sampling methods will be consistent with ASTM Method D-1452-80 and county, state and federal regulations.

Boring Installation and Soil Sampling

Direct push uses a 1.5-inch outer barrel with an inner rod held in place during pushing. Soil samples are collected by penetrating to the desired depth, retracting the inner rod and attaching a spoon sampler. The sampler is then thrust beyond the outer barrel into native soil. Soil samples are recovered in brass or stainless containers lining the spoon.

Soil removed from the upper tube section is used for lithologic descriptions (according to the unified soil classification system) and for organic vapor field analysis. If organic vapors will be analyzed in the field, a portion of each soil sample will be placed in a plastic zip-lock bag. The bag will be sealed and warmed for approximately 10 minutes to allow vapors to be released from the soil sample and diffuse into the head space of the bag. The bag is then pierced with the probe of a calibrated organic vapor detector. The results of the field testing will be noted with the lithologic descriptions on the field exploratory soil boring log. Soil samples selected for laboratory analysis will be covered on both ends with Teflon™ tape and plastic end caps. The samples will then be labeled, documented on a chain-of-custody form and placed in a cooler for transport to a state certified analytical laboratory.

Temporary Well Installation and Groundwater Sampling

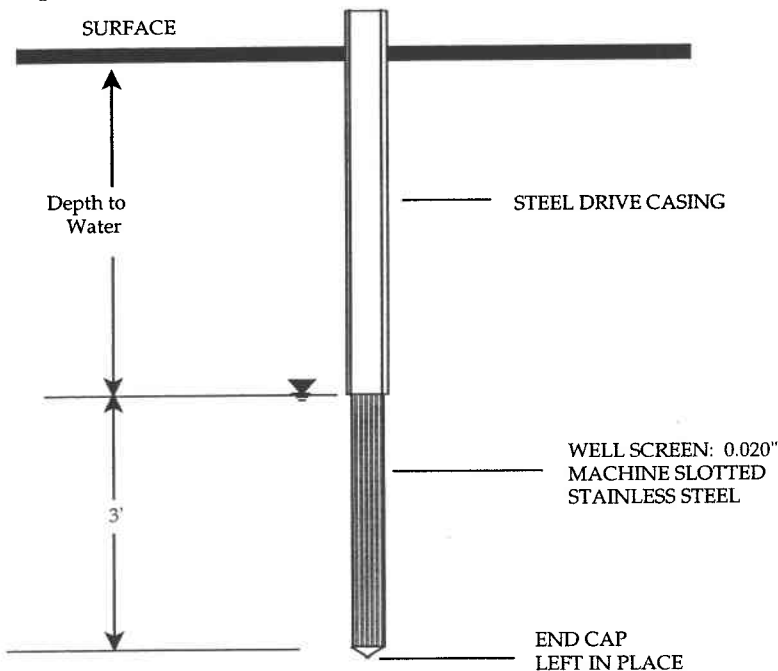


Figure 1

Groundwater samples are collected by removing the inner rod and attaching a 4-foot stainless steel screen with a drive point at the end (Figure 1). The screen and rod are then inserted in the outer barrel and driven to the desired depth where the outer rod is retracted to expose the screen. If enough water for sampling is not produced through the stainless well screen, a 1-inch PVC screen can be installed in the boring and the outer rod retracted to leave a temporary well point for collecting groundwater samples or water levels.

Monitoring Well Installation and Development

Permanent small-diameter monitoring wells are installed by driving the outer barrel and inner rod as described above. Upon reaching the desired depth the system is removed and 2-inch OD (1/2-inch ID) pre-packed PVC piping is installed. The well plug is created using granular bentonite. The well seal is constructed of cement and sealed at the surface with a conventional "Christy® Box" or similar vault. Monitoring wells are developed by surging the well with a small diameter bailer and removing 3 to 5 casing volumes of water until the produced water is clear.

Groundwater Sample Collection and Water Level Measurement

Prior to collecting groundwater from the wells the water levels are measured in all wells using an electronic water level gauge. Monitoring wells are prepared for sampling by purging three well bore volumes of water. Water is removed using small diameter bailers, a peristaltic pump, or manually using tubing with a check valve at the bottom. During removal of each volume, the temperature, pH and conductivity are measured and recorded on the field sampling form. Successive well volumes are removed until the parameters have stabilized or the well has gone dry. Prior to sampling, the well is allowed to recover to within 90% of the stabilized water levels.

Groundwater samples¹ are collected using small diameter bailers. The samples are decanted into laboratory supplied containers, labeled, recorded on a chain-of-custody form and placed on ice for transport to a certified laboratory.

¹ Small diameter wells often produce small sample quantities and are appropriate for analysis of volatile and aromatic compounds and dissolved metals analysis using VOA vials. Obtaining liter-size samples can be difficult and time consuming. Monitoring wells installed by the direct push method are most effective at sites where the subsurface soils are more coarse than silt, gasoline components are the key contaminants of concern, and water levels are not more than 25 feet below ground surface.

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Soil Sampling Procedures

Soil samples are typically collected in six-inch long, two-inch diameter brass tubes. If copper or zinc contamination is the subject of the investigation, stainless steel liners are used instead of brass. Soil sample locations are typically selected by field screening a portion of the soil for organic vapors using a calibrated organic vapor meter.

Once the sampling location has been determined, a small thickness of superficial soil is removed prior to collection, to prevent cross contamination. If the location being sampled has been exposed to the air for more than a few minutes, hand-tools will be used to dig at least 12 inches into the soil in order to collect as fresh a sample as possible. The sample is collected by pushing the tube into the soil by hand, or a rubber mallet may be used if the tube can not be driven by hand. If it is not possible to drive the tube into the soil, loose soil may be scraped from the freshly exposed surface and placed in the tube by hand.

Soil samples may also be collected using a hand auger and a slide hammer-driven sampler. The hand auger is advanced the desired depth into the soil, then withdrawn and replaced with the slide hammer sampler. The slide hammer sampler contains a 6-inch long by 2-inch diameter brass sample liner (or two 3-inch long liners) inserted inside the threaded core barrel, which is attached to the slide hammer by an extension rod. The core barrel is driven into the soil by the slide hammer, then withdrawn, unscrewed, and the sample liner removed.

Soil samples selected for laboratory analysis are immediately sealed on both ends with Teflon[®] lined plastic end caps, labeled, documented on a chain-of-custody form, and placed in a chilled cooler for transport to a state-certified laboratory.

To prevent cross-contamination of the samples, Clearwater personnel adhere to the following procedures in the field:

- A new, clean pair of latex or nitrile gloves are donned prior to collecting each sample.
- All hand-digging and sampling equipment is thoroughly decontaminated between each sample, by scrubbing equipment in a wash of Alconox[®] solution, followed by a double rinse in potable water. If required the second rinse will consist of distilled water.

- All purging equipment will be thoroughly decontaminated between each well, using the procedures previously described at the beginning of this section.
- During sample collection for volatile organic analysis, the amount of air passing through the sample is minimized. This helps prevent the air from stripping the volatiles from the water. Sample bottles are filled by slowly running the sample down the side of the bottle until there is a convex meniscus over the mouth of the bottle. The lid is carefully screwed onto the bottle such that no air bubbles are present within the bottle. If a bubble is present, the cap is removed and additional water is added to the sample container. After resealing the sample container, if bubbles still are present inside, the sample container is discarded and the procedure is repeated with a new container.

Laboratory and field handling procedures may be monitored, if required by the client or regulators, by including quality control (QC) samples for analysis with the groundwater samples. Examples of different types of QC samples are as follows:

- Trip blanks are prepared at the analytical laboratory by laboratory personnel to check field handling procedures. Trip blanks are transported to the project site in the same manner as the laboratory-supplied sample containers to be filled. They are not opened, and are returned to the laboratory with the samples collected. Trip blanks are analyzed for purgeable organic compounds.
- Equipment blanks are prepared in the field to determine if decontamination of field sampling equipment has been effective. The sampling equipment used to collect the groundwater samples is rinsed with distilled water which is then decanted into laboratory-supplied containers. The equipment blanks are transported to the laboratory, and are analyzed for the same chemical constituents as the samples collected at the site.
- Duplicates are collected at the same time that the standard groundwater samples are being collected and are analyzed for the same compounds in order to check the reproducibility of laboratory data. They are typically only collected from one well per sampling event. The duplicate is assigned an identification number that will not associate it with the source well.

Generally, trip blanks and field blanks check field handling and transportation procedures. Duplicates check laboratory procedures. The configuration of QC samples is determined by Clearwater depending on site conditions and regulatory requirements.

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Groundwater Monitoring and Sampling Field Procedures

Groundwater Monitoring

Prior to beginning, a decontamination area is established. Decontamination procedures consist of scrubbing downhole equipment in an Alconox® solution wash (wash solution is pumped through any purging pumps used), and rinsing in a first rinse of potable water and a second rinse of potable water or deionized water if the latter is required. Any non-dedicated downhole equipment is decontaminated prior to use.

Prior to purging and sampling a well, the static water level is measured to the nearest 0.01 feet with an electronic water sounder. Depth to bottom is typically measured once per year, at the request of the project manager, and during Clearwater's first visit to a site. If historical analytical data are not available, with which to establish a reliable order of increasing well contamination, the water sounder and tape will be decontaminated between each well. If floating separate-phase hydrocarbons (SPH) are suspected or observed, SPH is collected using a clear, open-ended product bailer, and the thickness is measured to the nearest 0.01 feet in the bailer. SPH may alternatively be measured with an electronic interface probe. Any monitoring well containing a measurable thickness of SPH before or during purging is not additionally purged and no sample is collected from that well. Wells containing hydrocarbon sheen are sampled unless otherwise specified by the project manager. Field observations such as well integrity as well as water level measurements and floating product thicknesses are noted on the Gauging Data/Purge Calculations form.

Well Purging

Each monitoring well to be sampled is purged using either a PVC bailer or a submersible pump. Physical parameters (pH, temperature and conductivity) of the purge water are monitored during purging activities to assess if the water sample collected is representative of the aquifer. If required, parameters such as dissolved oxygen, turbidity, salinity etc. are also measured. Samples are considered representative if parameter stability is achieved. Stability is defined as a change of less than 0.25 pH units, less than 10% change in conductivity in micro mhos, and less than 1.0 degree centigrade (1.8 degrees Fahrenheit) change in temperature. Parameters are measured in a discrete sample decanted from the bailer separately from the rest of the purge water. Parameters are measured at least four times during purging; initially, and at volume intervals of one well volume. Purging continues until three well casing volumes have been removed or until the well completely dewater. Wells which dewater or demonstrate a slow recharge may be sampled after fewer than three well volumes have been removed. Well purging information is recorded on the Purge Data sheet. All meters used to measure parameters are calibrated daily. Purge water is sealed, labeled, and stored on site in D.O.T.-approved 55-gallon drums. After being chemically profiled, the water is removed to an appropriate disposal facility by a licensed waste hauler.

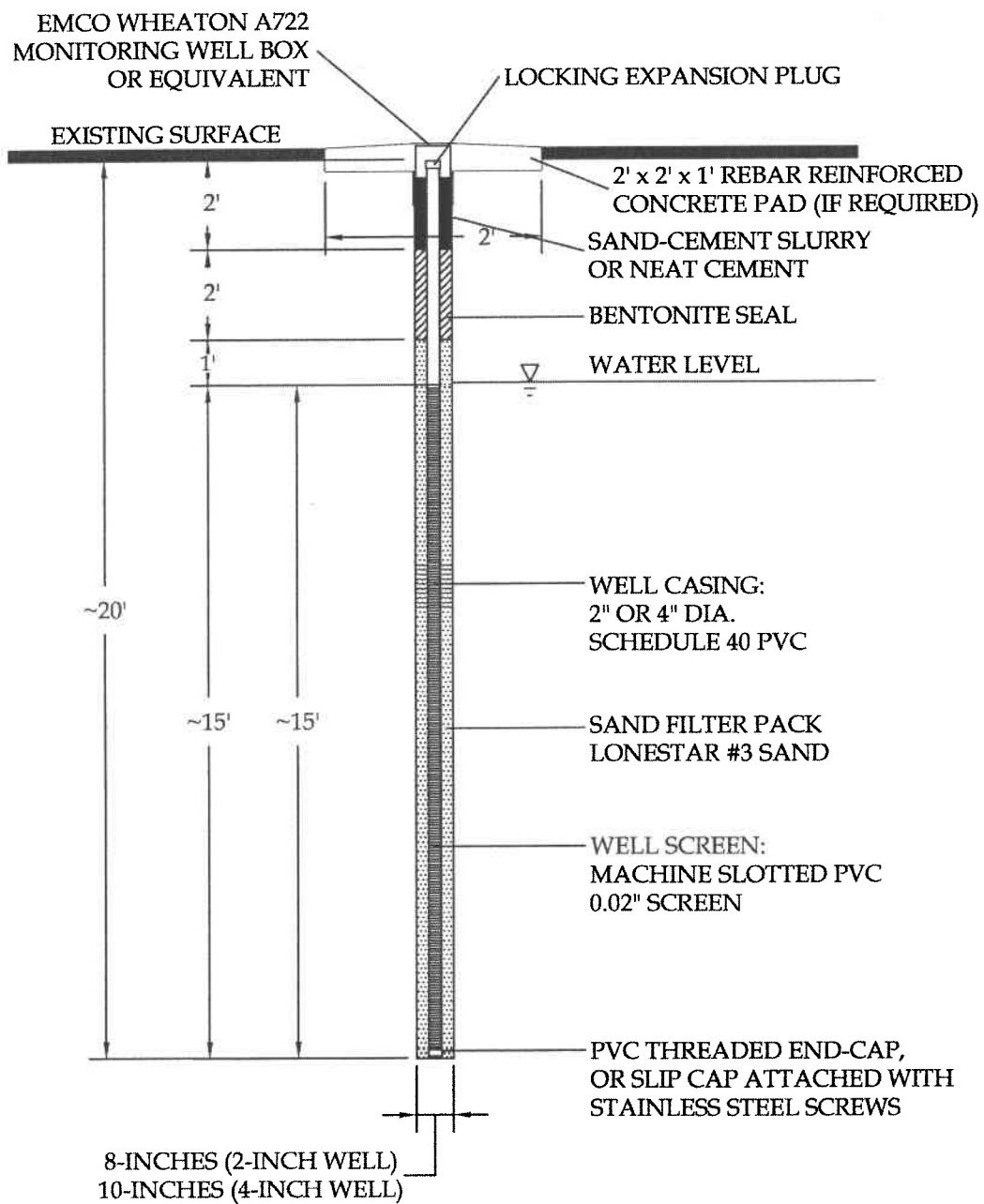
Groundwater Sample Collection

Groundwater samples are collected immediately after purging or, if purging rate exceeds well recharge rate, when the well has recharged to at least 80% of its static water level. If recharge is extremely slow, the well is allowed to recharge for at least two hours, if practicable, or until sufficient volume has accumulated for sampling. The well is sampled within 24 hours of purging or repurged. Samples are collected using polyethylene bailers, either disposable or dedicated to the well. Samples being analyzed for compounds most sensitive to volatilization are collected first. Water samples are placed in appropriate laboratory-supplied containers, labeled, documented on a chain of custody form and placed on ice in a cooler for transport to a state-certified analytical laboratory. Analytical detection limits match or surpass standards required by relevant local or regional guidelines.

Quality Assurance Procedures

To prevent contamination of the samples, Clearwater personnel adhere to the following procedures in the field:

- A new, clean pair of latex gloves is put on prior to sampling each well.
- Wells are gauged, purged and groundwater samples are collected in the expected order of increasing degree of contamination based on historical analytical results.



NOT TO SCALE

CLEARWATER GROUP		
Well Construction Detail		
Project No. AB021E	Date: 02/05	Figure 7
	Drawn by: MR	

APPENDIX D

**Regional Water Quality Control Board, North Coast Region letter
(December 8, 2004)**

Request for extension letter (January 11, 2005)



Terry Tamminen
Secretary for
Environmental
Protection

California Regional Water Quality Control Board North Coast Region

William R. Massey, Chairman



Arnold
Schwarzenegger
Governor

<http://www.swrcb.ca.gov/rwqcb1/>

5550 Skylane Boulevard, Suite A, Santa Rosa, California 95403
Phone 1-877-721-9203 Office (707) 576-2220 FAX (707) 523-0135

December 8, 2004

Mr. Franklin Wolmuth
Mortgage Deep Corporation of America
P.O. Box 640551
San Francisco, CA 94164-0551

Dear Mr. Wolmuth:

Subject: Corrective Action Plan Submittal
File: Texaco, 421 Santa Rosa Avenue, Santa Rosa, Case No. 1TSR059

Regional Water Board staff have reviewed the October 15, 2004 *SVE Feasibility Testing Report* and the Third and Fourth Quarter 2004 Groundwater Monitoring Reports prepared by Clearwater Group for 421 Santa Rosa Avenue in Santa Rosa. According to Clearwater Group staff, a Corrective Action Plan (CAP) is being prepared, which should be completed in December 2004.

We look forward to receipt of the CAP by January 17, 2005. The CAP must be prepared according to the requirements of Title 23, Article 11, Section 2725. The Feasibility Study portion of the CAP must evaluate and compare cleanup alternatives and their costs for the life of the project, including ongoing monitoring and reporting costs.

Please continue to include EPA Method 8260 for fuel oxygenates and lead scavengers in the sampling schedule. In addition, monitoring and sampling should be coordinated with the monitoring and sampling events conducted for 505 Santa Rosa Avenue. Ms. Diana Dickerson with Brunson Associates (the consultant for 505 Santa Rosa Avenue) can be reached at (707) 838-3027.

If you have any questions I can be reached at (707) 576-2675.

Sincerely,

Joan Fleck
Engineering Geologist

JEF:clh/120804_JEF_womuth421

Cc: Fire Inspector Andrea Jensen, Santa Rosa Fire Department
Mr. Jim Daly, Clearwater Group, 229 Tewksbury Avenue, Point Richmond, CA
94801

Jan 31
due to extend
liaison with owner
& architect

California Environmental Protection Agency

Recycled Paper



11 January 2005

Ms. Joan Fleck
North Coast Region
Regional Water Quality Control Board
5550 Skylane Blvd, Suite A
Santa Rosa, CA 95403

Re: Corrective Action Plan
Texaco
421 Santa Rosa Avenue
Santa Rosa, California 95404
Case No. 1TSR059


Dear Ms. Fleck:

On behalf of Mr. Franklin Wolmuth, Clearwater Group (Clearwater) would like to request an extension for the submission of the Corrective Action Plan (for the above mentioned site) from January 17 2005 to the 31st January 2005. This extension is requested due to extended liaison and co-ordination with the site owner and architect regarding current demolition works and future site construction activities.

Thank you for your consideration. It would be appreciated if you could notify me as to your decision as soon as possible. My email address is jho@clearwatergroup.com

Should you have any questions and comments related to this plan or the project, please do not hesitate to call me at (510) 307-9943 ext 231.

Sincerely,
Clearwater Group



Jim Ho
Principal Engineer